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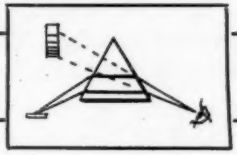

MARCH
1931

PROCEEDINGS

of the

Fifteenth Annual Meeting

UNIVERSITY OF VIRGINIA
CHARLOTTESVILLE, VIRGINIA

October 30, 31, and November 1, 1930

MINUTES OF THE MEETING

The fifteenth annual meeting of the Optical Society of America was held at the University of Virginia, October 30, 31, and November 1, 1930.

The meeting convened Thursday morning, October 30, the Society being welcomed by Dr. Edwin Anderson Alderman, President of the University.

THOMAS JEFFERSON

Thursday afternoon, October 30, the Society listened to an invited paper.

Some Aspects of the Scientific Work of Thomas Jefferson, by Prof. Walter S. Rodman, which gave a clear picture of Jefferson's varied scientific activities.

SESSION DEVOTED TO THE EXTREMES OF THE SPECTRUM

The session Friday afternoon, October 30, was devoted to papers on the extremes of the spectrum. The following papers were presented by invitation.

Optics of X-rays, by Prof. Arthur H. Compton.

Grating Measurements of X-ray Wave lengths and their Significance, by Dr. J. A. Bearden.

Optics of Radio-Transmission, by Prof. Ernest Merritt.

PUBLIC LECTURE ON RELIEF PICTURES AND PROJECTION IN RELIEF

On Thursday evening, October 30, Dr. Herbert E. Ives gave, by invitation, a lecture on *Relief Pictures and Projection in Relief*. The lecture was illustrated by special demonstrations of relief pictures including the stereoscope, the various stages of development of the parallax stereogram, the parallax panoramogram, and ending with demonstrations of two new types of projected pictures with stereoscopic relief.

BUSINESS SESSION

A brief business session of the society was held Saturday morning, November 1, President Jones presiding.

Informal reports of the secretary, the treasurer and the business manager of the journal were presented by the secretary. (Note: The society's fiscal year being identical with the civil calendar year, the officers' *formal* reports are made as of December 31 each year.)

In presenting the treasurer's report, the secretary read a telegram from Mr. Lomb regretting his inability to be present.

On a motion by Dr. Herbert E. Ives, the society directed the secretary to write a letter to Mr. Lomb expressing their regrets that he was unable to be present and their best wishes for his complete recovery.

FUTURE MEETINGS

The President announced the decision of the Council to hold a meeting in New York City in February and the annual meeting in Rochester, N. Y. in October.

On the President's invitation Dr. I. H. Godlove of the Museums of the Peaceful Arts, New York City, gave a short outline of the plan of their Exhibition on Color in connection with which sessions of the February meeting are planned.

VOTE OF THANKS TO THE UNIVERSITY OF VIRGINIA AND THE LOCAL COMMITTEE ON ARRANGEMENTS

Dr. W. E. Forsythe moved a vote of thanks to the University of Virginia and the local committee and all others who by their many courtesies and hospitality had contributed to a highly successful and enjoyable meeting. The motion was carried unanimously, and the secretary was instructed to communicate it to the President of the University and the local committee.

There being no other business, the business session was adjourned, and the reading of contributed papers taken up.

ATTENDANCE

The total registration was:

Members	53
Guests	29
Total	82

SESSIONS FOR THE READING AND DISCUSSION OF CONTRIBUTED PAPERS

Sessions for the reading and discussion of contributed papers were held as follows:

October 30, 9:15 A.M. Television, Theory of Vision and Optical Instruments

October 30, 3:00 P.M. Electro-optical Measurements

October 31, 9:00 A.M. Photometry, Colorimetry, Polarimetry and Kerr Effect

November 1, 9:30 A.M. Radiation, etc.

The authors' abstracts of these papers are appended.

MEETING OF THE COUNCIL

Sessions of the executive council were held as follows:

Wednesday, October 29, 3:15 P.M.
Wednesday, October 29, 8:20 P.M.
Thursday, October 30, 4:05 P.M.
Friday, October 31, 9:30 P.M.

(*Signed*) L. B. TUCKERMAN, *Secretary*

PROGRAM OF SESSIONS FOR CONTRIBUTED PAPERS

(TITLES AND ABSTRACTS OF PAPERS)

The abstracts were preprinted in the program subject to correction by the authors. Corrections that have been communicated to the secretary have been made in the abstracts reprinted below.

Thursday, October 30

9:15 A.M.

CONTRIBUTED PAPERS ON TELEVISION, THEORY OF VISION AND OPTICAL INSTRUMENTS

Herbert E. Ives **Bell Telephone Laboratories**

A MULTI-CHANNEL TELEVISION APPARATUS

A bar to the attainment of television images having a large amount of detail is set by the practical difficulty of generating and transmitting wide frequency bands. An alternative to a single wide frequency band is to divide it among several narrow bands, separately transmitted. A three channel apparatus has been constructed in which prisms placed over the holes in a scanning disc direct the incident light into three photoelectric cells. The three sets of signals are transmitted over three channels to a triple electrode neon lamp placed behind a viewing disc also provided with prisms over its apertures so that each electrode is visible only through every third aperture. An image of 13,000 elements is thus produced. For the successful operation of the multi-channel system, it is imperative to have very accurate matching of the characteristics in the several channels.

The present paper will appear in full in J.O.S.A.

Herbert E. Ives **Bell Telephone Laboratories**

SOME OPTICAL FEATURES IN TWO-WAY TELEVISION

The two-way television apparatus has been modified in several details, chiefly optical, since first demonstrated.[1] In place of scanning by blue light, light from both ends of the spectrum is employed, whereby more correct tone values of faces are obtained. Incandescent electric lamps are used instead of arc lamps to produce the scanning beams, and their large proportion of long wave energy is utilized effectively by a pair of caesium oxide, red-sensitive, cells added to the blue sensitive potassium cells previously used. At the receiving end, the discs have been furnished with condensing lenses over each hole, utilizing rays from a single large collimating lens focused on a small electrode glow lamp. A new general illumination of the booths has been provided of a yellow-green color to which neither the potassium or caesium cells are sensitive.

Bibliography:

[1] Bell System Technical Journal, July, 1930, p. 448.

The present paper will appear in full in J.O.S.A.

Herbert E. Ives **Bell Telephone Laboratories**

TELEVISION IN COLOR FROM MOTION PICTURE FILM

If a television scanning disc is placed close to the ridged film in a Kodacolor projector, and three photelectric cells are placed side by side in front of the projection lens, three sets of

photoelectric signals will be produced, each corresponding to one of the primary colors. It is not necessary to use the color filters ordinarily placed before the lens or color sensitive photoelectric cells, since the black and white strip images on the film contain the complete record of the characteristics of each colored image. The three sets of signals are transmitted over three communication channels and actuate a free color receiving apparatus previously described.[1]

Bibliography:

[1] Journal of the Optical Society of America, January, 1930, p. 11.

The present paper will appear in full in J.O.S.A.

Deane B. Judd **Bureau of Standards**

THE MIXTURE DATA EMBODIED IN THE TENTATIVE CURVES OF HECHT'S THEORY OF VISION

Dr. Selig Hecht[1] has recently proposed a modification of Thomas Young's theory of vision which has attracted considerable interest. To make his views specific he has put forward in a tentative way a set of response curves which he states possess the property of describing the facts experimentally determined by means of the mixture of color stimuli. In substantiation of this belief Dr. Hecht demonstrates that his curves are almost exactly duplicated by a transformation of the O. S. A. "excitation" curves which have been adopted widely as the standard description of the mixture relations characteristic of the normal visual mechanism.

If it could be shown that Dr. Hecht's curves duplicate exactly a transformation of the O. S. A. "excitaton" curves, the conclusion that his curves describe normal mixture data would be indisputable. Whether this conclusion is correct, however, cannot be judged from his own comparison because we cannot be sure that the apparently unimportant discrepancies are really negligible.

In the present paper a comparison of these two sets of curves is presented by a method which permits of the determination of the importance of the discrepancies found. It is shown that, in spite of the apparent agreement, Dr. Hecht's theoretical curves really embody mixture relations essentially different from those of the O. S. A. "excitation" curves; and, hence, his curves fail to describe the known facts arising from the mixture of color stimuli.

It is concluded that Dr. Hecht's methods of comparison are inadequate. But it should be stressed that Dr. Hecht's theory is not disproved by the findings of this paper; merely the first tentative set of curves has been shown to be unacceptable.

Bibliography:

[1] Selig Hecht, *The Development of Thomas Young's Theory of Color Vision*, J. O. S. A., *20*, 231–270; May, 1930.

The present paper will appear in full in J.O.S.A.

I. C. Gardner **Bureau of Standards**

THE CHROMATIC ABERRATION OF APOCHROMATIC MAGNIFYING SYSTEMS

The results of a series of tests on 17 apochromatic microscope objectives from 4 manufacturers and 10 compensating eyepieces from two manufacturers will be presented. The objectives were sensibly free from distortion and the average values of the lateral chromatic aberration for the objectives of the different manufacturers showed no important differences. The variation in the amount of compensation introduced by the different eyepieces was more significant than the variation found in the objectives. For the eyepieces the chromatic variation in distortion is an important factor in introducing the necessary compensation of the aberration of the objective.

Harold F. Bennett **Bureau of Standards**

THE RECIPROCAL SPHERICAL ABERRATION OF A LENS INCLUDING FIFTH AND HIGHER ORDERS

In this paper the reciprocal of the distance between the intersection of a ray with the axis and a fixed point on the axis is expressed as a power series in h, where h is the perpendicular distance from the ray to the fixed point. This fixed point of reference is ordinarily either the vertex or the center of curvature of the appropriate lens surface. Expressions are developed by which the coefficients of the series in the image space of any given plane or spherical surface may be computed if the corresponding series in the object space is given.

Supplementary formulas are then developed by which the aberrations may be referred to a different point such as the vertex or center of curvature of the succeeding surface. By means of these transfer formulas the computation may be carried through a lens system and a series expression for the aberrations obtained. Numerical applications and results are given and comparisons drawn with trigonometric ray tracing. Some relations to diffraction theory are also pointed out.

The present paper will appear in full in B. S. Journal of Research.

A. P. H. Trivelli and L. V. Foster **Research Lab. Eastman Kodak Co. & Scientific Bureau, Bausch & Lomb Optical Co.**

PHOTOMICROGRAPHY WITH WAVE LENGTH 365 mμ

By using a mercury arc lamp and Wratten filter No. 18-A we are able to isolate the mercury line 365 mμ for photomicrography. The microscope objectives were so built that both the mercury green line (546 mμ) and the ultraviolet line (365 mμ) are brought into the same focus. This makes focusing possible with Wratten filter No. 77, which isolates the mercury green line. By these means photomicrographs can be made by 365 $m\mu$ light by merely changing the filters. Examples of the results will be projected.

The present paper will appear in full in J.O.S.A.

David W. Mann **Jefferson Physical Laboratory, Harvard University, and Mann Instrument Co.**

MECHANICAL ACCESSORIES TO THE VACUUM SPECTROGRAPH

Methods of moving internal elements of the spectrograph while under vacuum are discussed from the viewpoint of the instrument designer and mechanician. It is the intention of the author to exhibit details of the spectrograph and related apparatus.

Thursday, October 30
3:00 P.M.

CONTRIBUTED PAPERS ON ELECTRO-OPTICAL MEASUREMENTS

Frederick Bedell **Cornell University**

REFINEMENTS IN LINEAR TIME-SCALE FOR CATHODE RAY OSCILLOGRAPH

In using a linear time-scale for a cathode-ray oscillograph, as in the stabilized oscilloscope[1] developed by Bedell and Reich, any tendency for the time-scale to be distorted, shown by a pinching together of successive wave lengths at left or right, is corrected by a biasing

or equalizing voltage applied to the amplifying tube for the time-scale, so that successive wave lengths are equal. This correction, readily made by an equalizer on the control panel of the instrument, is for most purposes sufficient. When highest accuracy is desired, a remaining error due to a cloud of ions between the plates of the oscillograph tube (affecting the vertical as well as the horizontal scale) may be avoided by applying a bias[2] to the plates of the oscillograph tube itself. A linear relation is thus obtained between the deflecting potential and the displacement of the cathode beam.

Bibliography:
[1] *Stabilized Oscilloscope with Amplified Stabilization*, F. Bedell and J. G. Kuhn, Rev. Sc. Instr., I, 227, Apr., 1930.
[2] *Linear Correction for Cathode Ray Oscillograph*, F. Bedell and J. G. Kuhn, Phys. Rev., 36, 993, Sept. 1, 1930.

John A. Tiedeman **University of Virginia**

(Introduced by J. W. Beams)

THE EFFECT OF FIELD STRENGTH AND FREE ELECTRONS ON THE BREAKDOWN TIME OF SPARK GAPS

The Lichtenberg Figure Method [1,2] has been used to study the time required for electrical breakdown in gases, or the time lag of the spark, as a function of the applied field strength and the number of free electrons present. The discharge of a spark gap impresses an electric field across the spark gap under investigation, and at the same time permits a measurable number of electrons to be photoelectrically ejected from the cathode. The time between the application of the potential and the initiation of the discharge is measured by the position of the dividing line between two Lichtenberg figures formed around similar electrodes placed upon a photographic plate and attached to lead wires in the ground side of the gaps. The spark gap under investigation is contained in a charged metal casing which serves to sweep out residual ions. The cathode is of zinc and the anode of steel. A biasing potential on the cathode prevents electrons from escaping in the gap until the impressed potential exceeds the biasing potential, at which time the electrons begin to be released photoelectrically. The source of ultraviolet light was a properly time condensed discharge in air. The intensity of the ultraviolet light could be varied by moving it various distances from the spark gap under investigation. An iron arc was also used in this way. The number of electrons liberated per second from the cathode was measured by an electroscope. Some of the data are given below:

Field applied to gap volts/cm.	Time necessary for breakdown: Intensity 15 $\times 10^{-8}$ sec	Intensity 1 $\times 10^{-8}$ sec	Intensity 0 $\times 10^{-8}$ sec
150,000	1.3	1.4	2.0
75,000	1.8	2.3	>100
50,000	4.2	4.8	
42,700	6.2	7.0	
40,000	7.1	>100	
37,500	>100		

The data show that there is a definite limiting time lag of the gap that is approached asymptotically at a definite field strength as the number of electrons in the gap is increased.

Bibliography:
[1] Pederson, Ann. d. Physik., *71*, 317; 1923.
[2] Tiedeman, Phys. Rev., *36*, 376; 1930.

Friday, October 31
9:00 A.M.

CONTRIBUTED PAPERS ON PHOTOMETRY, COLORIMETRY, POLARIMETRY AND KERR EFFECT

Harlan T. Stetson — **Perkins Observatory, Ohio Wesleyan University**

ON THE USE OF THE MACBETH ILLUMINOMETER IN THE MEASUREMENT OF THE BRIGHTNESS OF THE SOLAR CORONA

At the eclipse of 1925, the Macbeth Illuminometer was employed by a number of scientific observers for measuring the total illumination at the time of the eclipse on January 24th. From the discordant results published,[1] it was inferred that much of the difficulty lay in the indefiniteness with which the illuminometer was directed at the sun during the time of the eclipse.

During subsequent eclipse expeditions, 1926, 1927 and 1929, the apparatus was used by Stetson, Coblentz and Arnold,[2] in a fixed position directed to the sun at mid-totality. The right angled horn with diffusing screen added greatly to the convenience of operation and eliminated the difficulty of following the sun's motion. An important change in the design for eclipse purposes incorporates the arrangement of the several absorbing screens on two slides, one for the sky and one for the working standard. The new form was first put into operation in 1927, in Norway, but unfavorable weather prevented important results.

Measures of coronal brightness in Malaya, in 1929, have been recently reduced, the light curve being shown herewith. The measured brightness during mid-totality at the 1926 eclipse was 0.14 foot candles, and in 1929, 0.15 foot candles. There is some evidence that the illumination increases with increasing solar activity.

The apparatus is being used at the eclipse of October 22, 1930, in Niaufou, by Mr. Josef Johnson, Research Assistant of the Perkins Observatory.

The value of continued measurements of the brightness of the corona at times of total solar eclipses is enhanced by every addition of data, for it is by means of an accumulated series of such observations that we may hope to learn of the varying intensity of the coronal light with changing solar activity throughout the sun spot cycle.

Bibliography:
[1] Transactions of the Illuminating Society. *20*, No. 6, 1925.
[2] Astrophysical Journal, *66*, 65.

K. S. Gibson — **Bureau of Standards**

AN ILLUMINATION SPHERE FOR REFLECTOMETRY AND PHOTOELECTRIC SPECTROPHOTOMETRY

Plans for a new photoelectric spectrophotometer were briefly outlined at a previous meeting.[1] The design of the illumination sphere there noted has been completed. This design is such that the sphere may be used with the Martens photometer, not only with the photoelectric cell as originally planned, but also visually with undispersed light (with or without filters). The sphere is of the general type proposed by Sharp and Little, by Karrer, and by McNicholas, but differs in details of design and of the resulting manipulation and observation. The following quanities can be measured with the present sphere:

(1) Apparent normal reflectance for diffuse illumination. By virtue of the Helmholtz reciprocal relations (as developed by McNicholas),[2] this quantity is numerically equal to the absolute reflectance for undirectional normal illumination.

(2) Apparent 60° reflectance for diffuse illumination. This quantity closely approximates for most materials[2] the absolute reflectance for diffuse illumination. Reciprocally, the quantity measured numerically equals the absolute reflectance for unidirectional 60° illumination.

(3) The analogous quantities for transmitted light.

For both (1) and (2) the sphere as a whole is rotated, carrying the sample from one beam to the other in accordance with the best method of use of the Martens photometer, and enabling the comparison beam to originate in turn from two different regions of the sphere wall. This last feature should assist in making the brightness of the comparison beam equal to the average for the whole sphere, which is necessary if correct values are to be obtained.

Bibliography:
[1] Gibson, J.O.S.A. and R.S.I., *18*, 166; March, 1929.
[2] McNicholas, B. S., Res. Pap., No. 3, July, 1928.

E. M. Lowry — **Research Lab. Eastman Kodak Co.**

THE PHOTOMETRIC SENSIBILITY OF THE EYE AND THE PRECISION OF PHOTOMETRIC MEASUREMENTS

In this paper data are presented to show that for maximum photometric sensibility the brightness of the photometric field should be adjusted so that a brightness level of from 20 to 30 millilamberts is secured. At this brightness the difference fraction b/B has a value of 1.37 percent. Further the precision of photometric observations as expressed by the average percentage deviation, from the mean, of a single observation is 0.19 percent at the above mentioned optimum brightness level. At this same field brightness the maximum percentage deviation from the mean of a single observation was found to be 0.41 percent.

Bibliography:
[1] Nutting, P. G.: *Retinal Sensibilities Related to Illuminating Engineering.* Trans. Ill. Eng. Soc., *11*, 1, 1916.
[2] Blanchard, J.: *Brightness Sensibility of the Retina*, Phys. Rev., *11*, 81, 1918.
[3] Holladay, L. L.: *Fundamentals of Glare and Visibility*, J. O. S. A., *12*, 276, 1926.
[4] Uppenborn, F.: Lehrbuch d. Photometrie, p. 212.
[5] Dauber, J.: *Psychophysische Untersuchungen zur Photometrie.* Marbe's Fortschr. d. Psychol., *3*, 102, 1914.
[6] Wild, L. W.: *Electrician*, *60*, 122, 1907–08.
The present paper will appear in full in J.O.S.A.

Deane B. Judd — **Bureau of Standards**

PRECISION OF COLOR TEMPERATURE MEASUREMENTS UNDER VARIOUS OBSERVING CONDITIONS; A NEW COLOR COMPARATOR FOR INCANDESCENT LAMPS

The determination of the color temperature of incandescent lamps by visual comparison with a standard lamp previously calibrated radiometrically has heretofore been carried out at the Bureau of Standards either by mean of the 3° circular field of the rotatory dispersion colorimeter or by means of the 6° circular field of the Martens photometer. Preliminary to the construction of a color comparator which was to be designed to permit color temperature determinations with a maximum of precision, an investigation was made of the effect on precision of various observing conditions. It was discovered for one observer, corroborated to some extent by another observer, that: (1) The larger the fields to be compared as to color, the greater the precision of determination of color temperature; (2) the closer together the fields to be compared as to color, the greater the precision of determination of color temperature, but if the space separating the areas be black, observation is considerably more disturbed than if the space be of about the same color as the areas, themselves; and (3) use of both eyes gives no greater precision than the use of one eye, but if the one eye has to be held close to an artificial pupil, the precision is lowered.

It was also discovered that the retina of an apparently normal observer may be seriously asymmetrical in sensitivity; that is, a serious discrepancy in color temperature may result simply from interchanging the areas to be compared or from changing the shape or size of the field; this finding serves to emphasize the importance of using a strict substitution method in comparing lamps as to color temperature. The new color comparator which was constructed during the course of these preliminary measurements permits the visual determination of color temperature with a precision two or three times as great as that by the instruments previously used for this purpose at the Bureau of Standards.

The present paper will appear in full in B. S. Journal of Research.

William G. Exton — **Prudential Insurance Co. of America**

ELECTRO-SCOPOMETRY

The present paper deals with an attempt to apply photo-electricity to measuring devices designed for the colorimetry and turbidimetry of laboratory medicine which were shown the Society on former occasions.[1,2,3,4] The instrument consists of two photo-electric cells, a rugged short period galvanometer and two fixed resistances in a simple Wheatstone bridge circuit. All connections are permanent. There are no electrical adjustments and the balanced circuit avoids the need of batteries, etc., for maintaining constancy of illumination and plate voltage.

Besides advantages in the way of unusual sensitivity, freedom from personal equations of observers, and avoidance of standardizing troubles, the Electro-Scopometer has proven remarkably stable in use and capable of reproducing calibrations. Its operation is so simple and rapid that routine and untrained workers can measure color and turbidity with an accuracy equal to or exceeding that now characteristic of research in this field.

After touching on some of the conditions peculiar to laboratory medicine the Electro-Scopometer and some of its applications are described.

Bibliography:

[1] Exton, Wm. G.: *Turbidimeter*, J.O.S.A. & R.S.I., 6, 414; 1922.

[2] Exton, Wm. G.: *A New and Direct Method of Measuring the Cloudiness of Liquids* (Scopometry), J.O.S.A. & R.S.I., *11*, 126; 1925.

[3] Exton, Wm. G.: *A New Method of Colorimetry*, J.O.S.A. & R.S.I., *14*, 134; 1927.

[4] Exton, Wm. G.: *Scopometry, Archives of Pathology and Laboratory Medicine*, *5*, fol. 49, 1928.

R. V. Baud — **The Westinghouse Electric & Mfg. Co.**

CONTRIBUTION TO STUDY OF EFFECT OF ELLIPTICAL POLARIZATION UPON ENERGY TRANSMISSION

This paper contains the equation for the energy transmission in a polarized light equipment that is composed of lenses, two crossed polarizing prisms, two crossed mica plates in 45° position with respect to the prisms, and a light source that produces "white" light. This equation is as follows:

$$E = \left[\cos^2 2\beta + \sin^2 2\beta \cos^2 \left\{ \frac{(n_1' - n_2')\lambda}{(n_1 - n_2)\lambda'} - 1 \right\} \frac{\pi}{2} \right] \sin^2 \frac{\phi'}{2} E_0$$

where E_0 is the energy incident on a small area of the specimen, E the final energy as transmitted through the instrument for the same area of the specimen, ϕ' the phase shift in the specimen for a wave length λ', n_1' and n_2' the indices of refraction for the mica plates for a wave length (λ', n_1 and n_2 the indices of refraction for the mica plates for a wave length) λ corresponding to circular polarization, and β the angle between the axes of refraction of the specimen and the axes of the mica plates.

The present study of the energy transmission is primarily a continuation of previous photoelastic researches, see references below. However, it is believed that the equation given will be of interest and practical use not only for workers in the field of optical stress analysis, but also for investigators working with the same equipment along other lines.

Bibliography:
[1] *Further Development in Photoelasticity*, R. V. Baud, J.O.S.A. & R.S.I., *18*, 5, 1929.
[2] *The Analysis of the Colors Observed in Photoelastic Experiments*, R. V. Baud and W. D. Wright, *J.O.S.A.*, *20*, 7; 1930.
The present paper will appear in full in J.O.S.A.

E. C. Stevenson and J. W. Beams **University of Virginia**

A PRECISE METHOD FOR DETERMINING THE KERR ELECTRO-OPTICAL EFFECT IN GASES

The method[1] used for determining the Kerr electro-optical effect or electric double refraction in gases has been extended and made to yield greater precision. Light from a mercury arc or incandescent strip filament lamp passes through filters or a monochromator, is made parallel by a lens, and plane polarized by a polarizing prism. It then passes between two oppositely charged parallel metal plates (Kerr cell) the lines of force making an angle of 45° with the plane of vibration of the entering light, then a second or analyzing prism, and is brought to focus by a lens on the surface of a vacuum photoelectric cell, previously tested for linearity. The analyzing prism is oriented at any desired angle and, from ratios of light intensities measured with the photoelectric cell and an electrometer for particular settings of this prism, the amount of double refraction can be calculated. This method of measuring the double refraction gives better precision than the well known Brace half shade method. The intensity of the source is maintained constant by the use of a second photoelectric cell in series with a galvanometer. The polarizing and analyzing prisms together with the Kerr cell are enclosed in a heavy steel tube with glass windows in the ends to permit the passage of the light. The metal plates of the Kerr cell are insulated from each other and from the tube by bakelite. The connections are made through ordinary spark plugs. Placing the two prisms inside the tube makes it possible to study gases at a few hundred atmospheres pressure, without introducing errors due to strains in the windows. It gives the advantage of increased density and dielectric strength of the gas. Gas pressures are measured on a special spring gauge calibrated by a piston gauge, and electric potentials are obtained from a 5 kw x-ray transformer feeding a condenser through two kenotrons in parallel. The potentials are measured by the use of a long continuous flow water resistance. Any desired temperature between 0° and 80° C is obtained and kept constant to 0.05° C by immersing the steel tube in a suitable liquid, thermostatically controlled.

Bibliography:
[1] Beams and Stevenson, Phys. Rev. A, *35*, 1440, 1930.

J. W. Beams **University of Virginia**

SOME IMPROVEMENTS IN THE KERR CELL METHOD AND ITS APPLICATION TO THE STUDY OF THE TIME OF APPEARANCE OF THE SPECTRUM LINES OF HELIUM

Experimental methods are given by which the proper constants of the apparatus used in the Kerr Cell arrangement for measuring short time intervals[1] can easily be determined. Impulsive surges are impressed upon the wires leading to the Kerr Cell, and the potential across the cell measured by a spark gap intensely irradiated with ultraviolet light. From the value of this potential, determined with various lengths of lead wires, different amounts of resistance

and various sizes of Kerr Cells, the shortest time of optical cut off can be obtained. The methods of testing for potential reflections and oscillations in the Kerr Cell, including a rotating mirror arrangement, Lichtenberg figure method, and a procedure based upon the rapid diffusion of luminous metallic vapor from the electrode surface toward the center of the spark gap, are described.

Utilizing constants that give the minimum time of optical cut off, the method has been applied to the study of the order of appearance of the visible spectrum in the initial stages of a condensed discharge through helium. The previous results[2] have been extended and a study made of the effect of pressure on the time of appearance of the lines. At the higher pressures (0.1 to 0.5 atmospheres) the lines appear very broad. A strong continuous spectrum appears in the very initial stages. The parahelium lines 5016 and 4922 appear before the orthohelium lines 4472, 5876 and 4713. The time between the appearance of 5016 (2^1S-3^1P) and 5876 (2^3P-3^3D) was found to decrease with increasing pressure which supports the conclusion of Ornstein[3] that the singlet levels are more readily excited by electron impacts than the triplet levels. Further that the orthohelium lines may result from secondary processes.

Bibliography:
[1] Beams, Phys. Rev., *35*, 24, 1930.
[2] Beams and Rhodes, Phys. Rev., *28*, 1147, 1926.
[3] Ornstein, Jour. Franklin Inst., *208*, 589, 1929.

Arthur Bramley **Bartol Research Foundation**

MODULATION OF LIGHT WAVES IN WATER

In investigating the effect of radio waves on the frequency of the light passing through a Kerr cell, a change in frequency of certain of the lines of the mercury and iron arc towards the red was found.[1] Further investigation showed that the light passing through the cell was highly scattered and that this scattered light showed the wave-length change of 0.06A towards the red. In the original experiments, where the light was examined with a spectrograph, the spectrogram showed either a displacement of the position of the line towards the red or an unsymmetrical broadening without a change in the position of the maximum density, depending on the intensity of the scattered and unscattered light and on the form of the line emitted by the source.[2] These displacements are too large to be accounted for by the modulation of the light by the radio waves. These displacements are independent of the frequency of the radio waves and of the plane of polarization of the light. Both are contradictory to theory of electromagnetic modulation.

The broadening of spectral lines towards the red by 0.05A through scattering in liquids[3] and the symmetrical displacement of the lines of scattered light towards the red and the blue[4] both arise possibly from perturbing effect of neighboring molecules on the frequency of the vertical oscillators producing the scattering.[5] The results obtained by the writer for the magnitude of the change in frequency of scattered light agree with the results obtained by Cabannes and Gross for 90° scattering as we should expect if they were the same phenomena since the construction of the cell makes it possible for light scattered at various angles to leave the cell at a small angle with the primary beam.

The origin of the scattered light is probably the metallic ions brought into solution from the electrodes by the high frequency field which also is shown by the absorption bands of the liquid for high frequency radio waves.

Bibliography:
[1] J. of F. I., *207*, p. 316, March, 1929; Phys. Rev. (A), *33*, 279.
[2] Phys. Rev. (L), *34*, 1061.
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Saturday, November 1

9:30 A.M.

CONTRIBUTED PAPERS ON RADIATION

A. H. Taylor — **Lighting Research Laboratory, Nela Park**

ULTRAVIOLET RADIATION FROM THE SUNLIGHT (TYPE S-1) LAMP

The Sunlight (Type S-1) lamp, which made its debut about a year ago, furnishes light of a color appreciably whiter than that from an ordinary gas-filled tungsten lamp, together with biologically-important ultraviolet radiation. Physically, it is a lamp combining incandescent tungsten with a mercury arc, enclosed in a special bulb having a high transmission in the region of 3000 Angstroms (λ3000), and a rapidly decreasing transmission for shorter wave lengths, becoming negligible below λ2700. It operates on a special transformer, and starts automatically when the current is turned on.

The distribution of energy in the spectrum of a Sunlight (Type S-1) lamp, chosen as representative of a group of 15 new lamps, has been carefully measured from the shortest wavelength emitted to λ7400. Energy values for each of the important spectral lines from the arc have been evaluated, also the continuous spectrum component in bands 100A wide. The measurements were made at rated voltage under two different conditions as follows: (A) in open air, axis vertical; (B) in open air, axis vertical, with temperature artificially altered to reproduce the electrical conditions existing in the lamp when operated in a Sunlamp reflector. The measurements were made for energy radiated in a direction normal to the plane of filament and electrodes, and energy values are expressed in percentages of the *total energy radiated in this direction*. The table below summarizes the results for important spectral regions.

	Per cent of total energy	
Wave-length region	Operated in open air	At temperature of operation in sunlamp
Shortest to λ2800	0.03	0.05
λ2800 to λ3200*	1.65	2.45
λ3200 to λ4000	1.56	2.55
λ4000 to λ7400†	9.50	7.8
Total, shortest λ to λ7400	12.74	12.85

* Biologically-important ultraviolet region.

† Visible spectrum.

The present paper will appear in full in J.O.S.A.

B. T. Barnes — **(Lamp Development Laboratory), Incandescent Lamp Dept., General Electric Co.**

ENERGY FLUX OF WAVE LENGTHS SHORTER THAN 3150A FROM THE GENERAL ELECTRIC SUNLAMP UNIT

The spectral distribution of energy flux from the Type S-1 lamp, the source of radiation in the General Electric Sunlamp, has been determined by means of a quartz monochromator and thermopile. The experimental method and detailed results will appear in an article by

the author in the Physical Review. The ratio of the amount of ultraviolet radiation below 3200A received from the Sunlamp unit to that from the lamp without reflector has been determined in this laboratory by Miss Easley.[1] She has also measured the average temperature of the mercury pool with the lamp in and out of the reflector. The changes in the relative intensity of the principal ultraviolet lines with varying mercury pool temperature have also been determined.[1] Luckiesh[2] has published curves for the reflectance of polished aluminum and aluminum oxide powder. By taking the average of data from these two curves approximate values for the relative reflectance at different wave lengths of the oxidized aluminum reflector are obtained. Correlating all these data, the energy flux in each of the principal ultraviolet bands below 3200A may be computed. The results indicate that the energy flux per cm^2 at one meter distance directly below the Sunlamp unit is 67 microwatts for the group of lines at 3130A, 23 for the lines at 3024A, 12 for the line at 2967A, 3 each for the 2894 and 2804A lines, 2 for 2650A, and 0.3 for 2537A. The figures refer to normal operation with 115 volts on the primary of the transformer. These data are not directly comparable with those given by Coblentz[3] since he measured the radiation from the Sunlamp without the screen. However, measurements made in this laboratory show that without the screen the energy flux density of wave lengths shorter than 3200A averages 126μw (microwatts) per cm^2 at 1 meter distance. From Coblentz's data a corresponding figure of 96μw per cm^2 at 36″ distance is obtained. The agreement is satisfactory since the output of individual lamps may differ from the average by 20 percent. Data published by Gordon and Benford[4] is in apparent disagreement with ours because their reflector gave a broader less concentrated beam than the ones measured by Miss Easley.[1] Taking this into account the agreement is very satisfactory.

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[1] W. E. Forsythe, B. T. Barnes & M. A. Easley, G. E. Rev., *33*, June, 1930.
[2] M. Luckiesh, J.O.S.A., *19*, 1, 1929.
[3] W. W. Coblentz, J.A.M.A., *95*, 411, Aug. 9, 1930.
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W. E. Forsythe & F. L. Christison (Lamp Development Laboratory), Incandescent Lamp Dept., General Electric Co.

THE ABSORPTION OF RADIATION FROM DIFFERENT SOURCES BY WATER AND BY BODY TISSUE

There are a number of infrared or total radiation devices on the market intended for therapeutic purposes which use as the source of the radiation, heaters that vary from low temperature blackened iron surfaces to high temperature tungsten lamps. In the use of these infrared radiators it is important to know whether the radiation is to be absorbed in a very thin layer near the surface of the body or whether it is desired to have the radiant energy penetrate deep into the tissue, because as shown in what follows, it is possible by the selection of the source of radiation to determine whether the radiation that is not reflected from the surface shall be absorbed in a very thin layer near the surface or whether a considerable portion of it shall penetrate deep into the tissue of the body. Since the body is made up of a very large percentage of water, radiation that will not go through water will not penetrate very deep into the body tissue. The transmission of different thicknesses of water has been calculated for the radiation from four different sources: iron heater at 1000° K., carbon lamp at 2150°K., tungsten lamp at 2970°K., and radiation from the sun. Cartwright[1] has presented some data on the spectral transmission of the human cheek. Making use of these data the amount of radiation from the four above sources transmitted through different thickness of body tissue has been calculated and the results given in the table. From these results it can be seen that if it is desired to have the radiation penetrate deep into the body tissue the high temperature source should be used.

Transmission of radiation from different sources through different thickness of water and body tissue

Flesh	Iron heater 1000°K.	Carbon lamp 2150°K.	Tungsten lamp 2970°K.	Sun
1 mm	0.58%	15.0%	30.0%	29.0%
1 cm	.02	.9	1.9	2.3
Water				
1 mm	3.1	35.	66.	85.
2 mm	1.4	28.	59.	81.
5 mm	.5	20.	51.	76.
1 cm	.25	15.	43.	71.
2 cm	.10	11.	36.	65.
1 cm water and 1 mm flesh			19.	
1 cm water and 1 cm flesh			1.2	

Bibliography:
[1] J.O.S.A., *20*, 81, Feb., 1930.

The present paper will appear in full in J.O.S.A.

F. L. Mohler **Bureau of Standards**

INTENSITY DISTRIBUTION IN THE EMISSION SPECTRUM OF CÆSIUM

The spectrum was excited in a thermionic discharge between an axial cathode and a cylindrical anode with vapor pressures usually between .08 and .8 mm and discharge current of the order of .5 amp at 6 volts. Under these conditions, the continuous spectrum from recombination of cæsium ions and electrons as well as the line spectrum of neutral cæsium is emitted. Intensity measurements were made by direct visual and photographic matching of the discharge spectrum with the spectrum of a calibrated tungsten strip lamp. Results on line intensities have been plotted with the log of the intensity in quanta per second as ordinates and the log of the effective total quantum number, n (square root of the Rydberg denominator), as abscissæ. Then the line intensities in each series fall in a curve which is closely linear for n greater than 5 and the linear portions of the curves are parallel for different series. In the range of discharge conditions specified the slopes remained between 5.5 and 6.0 but at low pressure the slope becomes much greater. That is, the intensity varies inversely as the 5.5 power of n or faster.

In so far as the plots for different series approximate parallel lines the intervals between these lines measure the intensity ratios between series. These ratios remained nearly 1 to 10 to 25 for the sharp, diffuse and fundamental series.

C. Boeckner **Bureau of Standards**

PROBABILITIES OF RECOMBINATION INTO THE 1S STATE OF CÆSIUM

Measurements were made of the intensity distribution in the continuous emission band, appearing at the 1S series limit of cæsium using a low voltage thermionic discharge in the vapor as a source. The wave length range covered lay between the series limit at 3184A and about 2750A. The methods of photographic densitometry were employed and a tungsten strip lamp in quartz was used as a comparison source.

From the variation of intensity with wave length and the velocity distribution of the discharge electrons (obtained from probe wire measurements) were computed the relative probabilities of recombination of free electrons into the 1S state as a function of their initial veloci-

ties. The method is that given by Mohler and Boeckner.[1] Previous work has shown that the probability of recombination into the 2P and 3D state of cæsium varies approximately inversely as the square of the velocity of the free electron, a relation which is also predicted by quantum mechanics for recombination into any level of a hydrogen atom. The present measurements show that the probability of recombination into the 1S cæsium level falls off much more rapidly with the velocity; for electron speeds greater than .15 volts more nearly as the inverse fourth power.

From the probability of recombination with emission of light a thermodynamical relation given by Milne enables one to deduce the probability of the inverse process, namely, the absorption of light and the ejection of a photoelectron. This latter probability has been measured directly as a function of wave length by Mohler and Boeckner and by Lawrence and Edlefsen. There are some discrepancies between the measurements of these different workers. It is found, however, that the absorption wave length curve deduced from recombination probabilities lies between the two curves obtained by direct measurement and agrees with either within the experimental error.

Bibliography:
[1] Mohler and Boeckner, Bur. Stds. J. of Res. No. 2, 489; 1929, Mohler, Phys. Rev. Sup., 1, 216; 1929.

Frederick L. Brown **University of Virginia**

FINE STRUCTURE OF COPPER LINES IN THE VISIBLE

The brighter lines given by a copper vacuum arc were examined with a Fabry-Perot Interferometer using separators of 2.7, 5.4, and 10.8 mm. Three lines 5782 ($m^3D_2-2^3P_1$), 5700 ($m^3D_2-2^3P_2$), and 4705 ($a^4F_4-c^4D_4$) appear to be double. The separation of the components is about 0.20 wave number units in each case. For 5782 and 5700 the component of longer wave length appears to be sharper than the other and about three times as intense. For 4705 the components are more nearly equal, but one of them must be more hazy or complex than the other for with the 10.8 separation only one set of rings is observed against a darkened background. The notation is that of Shenstone.[1] Burns and Walters[2] suspect the 3^3P_2 level of being double, and state that the c^4D levels present some difficulties as D_4 appeared to be single and D_1 multiple.

The other bright lines in the visible appeared to remain sharp except that 5106($m^3D_3-2^3P_2$) is widening at 10.8 mm, but the separation is less than for the three lines measured. The measurements are more or less in agreement with Wali-Mohammad.[3]

Bibliography:
[1] Shenstone, Phys. Rev., 28, 449–474.
[2] Burns and Walters, Pub. Alleghany Observatory, 8, 27–35.
[3] Wali-Mohammad, Astrophys. Journ., 39, 185–203; 1914.

L. B. Snoddy **General Electric Company**

(Introduced by J. W. Beams)

THE DARK CURRENT TIME IN CONDENSED DISCHARGES IN AIR AT ATMOSPHERIC PRESSURE

In order to measure the time during which current flows in condensed discharges prior to the appearance of luminosity it is necessary to determine the time at which the discharge is initiated as well as the interval between the initiation and the appearance of luminosity. In this experiment the discharge is initiated by ultraviolet light from another spark gap. The light from this tripping gap is focused by a quartz lens on the cathode of the second gap. The combined light from the two gaps after reflection by a rotating mirror is focused by another

lens on a photographic plate. The separation of the images on the plate gives a measure of the dark current time. By using the high speed rotating mirror developed by Henriot[1] and Hunguenard and improved by Beams,[2] a resolving power of 1.7×10^{-7} second was obtained. The dark current time was found to be a function of the electrode geometry. For symmetrical hemispherical electrodes 4 mm apart the time is not greater than 1.7×10^{-7} second. This time increases to approximately 3×10^{-6} second for a gap with two spherical electrodes, the positive 25.7 mm in diameter and the negative 1 mm in diameter. As near as this method is capable of determining, in all cases the luminosity appears at the same time throughout the gap.

Bibliography:
[1] Henriot and Hunguenard, Jour. d. Phys. et Ra., *8*, 443; 1927.
[2] Beams, J. W., Phys. Rev., *35*, 24; 1930.

A. H. Pfund **Johns Hopkins University**

A PLATE REFRACTOMETER FOR DEMONSTRATIONS

The instrument consists of a piece of plane-parallel glass (plate glass) about 5 cm square and of about 3 mm thickness. The lower side of the glass is painted white. Illumination is effected by means of an auto headlight lamp whose filament-image is projected downward on the glass-paint interface by means of a short-focus convex lens. This image ought to be less than 0.5 mm in diameter but of great sharpness and brilliancy. When viewed in a darkened room, the plate reveals a central brilliant spot surrounded by a black disc. The boundaries of this disc are defined by the critical angle between glass and air. If, now, the upper glass surface be moistened with water, a second and larger ring also appears. This ring is due to total reflection at the water-glass interface. By using a piece of glass on which a millimeter scale is ruled and by covering this with white paint, it is possible to read off circle-diameters to 0.1 mm with a reading glass. If the thickness of this plate be about 5 mm, refractive indices may be measured to the third decimal place. By making use of multiple reflections it is possible to construct a precision instrument whose performance rivals that of the best of present-day refractometers.

INTERFERENCE IN THE SOLAR CORONA*

By Winthrop R. Wright and Heber D. Curtis
[Department of Physics, Swarthmore College, Swarthmore Pa. and
Detroit Observatory, Ann Arbor, Mich. Received Jan. 6, 1930]

Introduction

During the past twenty years the eclipse programs of the expeditions sent out by the Sproul Observatory of Swarthmore College have centered upon the problem of motion in the solar corona. The desirability of attacking the problem from many sides led Professor J. H. Pitman to suggest, when the expedition to Yerbaniz, Mexico, was being planned in 1923, that the method invented by Buisson Fabry and Bourget[1] for determining radial velocities in the Orion Nebula might well be applied to finding of coronal motions. The method involves the observation of the interference pattern due to one of the stronger coronal lines (preferably 5303A or 3388A) and, if successful, will be expected to yield detailed information of the rotation of the corona from the Doppler effect and a much more precise wave length for the line in question.

Accordingly, Wright constructed the first of the interferometers to be described later, and employed it at Yerbaniz, Mexico, in 1923. Later, Curtis who has enjoyed the privilege of participation in four recent Swarthmore College eclipse expeditions, coöperated with Wright in the investigation with two interferometers of his own construction. Throughout the subsequent progress of the attempted research the joint authors of this paper have enjoyed the advantage of constant collaboration and discussion in the problems presented. While certain features are common to the individual methods employed, the differences in the various instruments are at least partially intentional, from the conviction that all promising variations in the method of attack might well be given a trial in a problem so close to the limit of present observational methods.

Interferometers of various designs have now been used by the authors at four recent eclipses:—at Yerbaniz, Mexico, in 1923; at New Haven, in 1925; at Benkoelen, Sumatra, in 1926; and again at Takengon, Sumatra, in 1929. With the various modifications made in the interferometers, different orders of interference, etc., it is not too much to say that we have now attacked the problem eight times at four different eclipses. While no definite positive results have been secured, the authors are convinced that the problem is of sufficient importance to warrant the

* See also Sproul Observatory Publications No. 11.

[1] Buisson Fabry and Bourget, Aph. J. *40*, 241; 1914.

publication of these investigations, and a discussion of the possibility of making successful interferometric observations on the corona.

Throughout this paper it will be necessary to make constant reference to the different instruments employed. While a more detailed description of each of these will be given later, these interferometers will be briefly mentioned at this point, with the abbreviation adopted for all subsequent reference to the instrument.

I. Sproul Observatory interferometer for the green line 5303A. Constructed by Wright at Swarthmore. Abbreviated to,—SOG.

II. Sproul Observatory interferometer for the ultraviolet line 3388A. Constructed by Wright at Swarthmore. Abbreviated to,—SOUV.

III. Allegheny Observatory interferometer for the green line 5303A. Constructed by Curtis at the Allegheny Observatory. Abbreviated to,—AOG.

IV. Allegheny Observatory interferometer for the ultraviolet line 3388A. Constructed by Curtis at the Allegheny Observatory. Abbreviated to AOUV.

II. Order of Interference, Magnification, etc.

It is possible that for the present problem the choice of separation in the etalon element should be guided more by general theoretical considerations than by the experience derived from observations with prism spectrographs. The green coronal line has often been recorded with prism spectrographs of from one to three prisms, and by Campbell[2] with a six prism train composed of four large compound and two large simple prisms, with an effective "order of interference" of approximately 50,000.

The limiting order of interference, N, is a function of the atomic mass, m, and the absolute temperature, T, in accordance with the formula,—

$$N = 1.22 \times 10^6 \sqrt{m/T_{\text{abs}}}$$

As one may conservatively use half this limiting order in practice, the following table will indicate advisable limits to the etalon separation:—

Table 1. *Advisable upper limits of etalon separation for various atomic masses and temperatures*

Atomic mass	2,000°	3,000°	4,000°	5,000° abs
H = 1	3.6	2.9	2.6	2.3 mm
2	5.0	4.1	3.6	3.2
He = 4	7.3	5.8	5.0	4.5
10	11.5	9.5	8.1	7.3

For the brightest and innermost part of the corona we should allow for a temperature of 5,000° abs, though the outer portions may be much

[2] Campbell, Aph. J., *10*, 186; 1899.

cooler; some allowance should also be made for the effect of convection currents in broadening the lines. If the corona be due to a form of hydrogen, the above table indicates that the separation should not be much greater than about 2.3 mm, corresponding to an interference order of 8,700. Wright used an etalon of 2.5 mm throughout in SOG and SOUV. Curtis employed 3.75 mm in 1925, changing to 1.0 mm (order of interference 3,800) for the 1926 eclipse at Benkoelen, a separation which should permit interference for matter of any atomic mass at any probable coronal temperature.

Freeman's suggestion[3] that the coronal lines might be due to argon was published while preparations were being made for the 1929 eclipse. Argon's higher atomic mass (40) would make possible the use of much higher orders of interference. Freeman also predicted that the line at 5303A should be double. Although the evidence for this identification was very weak, it seemed well worth while to give this hypothesis a trial. A new separator was accordingly made for AOG of 6.5 mm, giving an interference order of 24,500. which should split 5303A if this line were double. At the same eclipse, a 5.0 mm etalon was used in AOUV, giving an order of 30,000; the various etalons and orders employed are tabulated in Tables 2 and 3.

We are indebted to Professor James Barnes of Bryn Mawr College for the loan of the platinized quartz plates used in SOUV, to Dr. Keivin Burns of the Allegheny Observatory for helpful advice and suggestions, and to Dr. W. F. Meggers of the Bureau of Standards who very kindly silvered the glass etalons or platinized the quartz ones used in the other interferometers[4]

[3] Freeman, Aph. J., *68*, 177; 1928.

[4] The specifications for such etalon plates may possibly be of interest to observers in allied fields.

Each plate to be 80 mm in diameter and 10 to 12 mm thick. The rear surfaces should be plane at least to 1 wave; the front (opposing) surfaces must be plane at least to 1/20 wave over a central area 6 cm in diameter; the edges of these faces may fall off a little in accuracy. The etalon plates must *not* have precisely parallel faces, but should make an angle of 3 to 8 minutes of arc with each other, and a mark (a small arrow) should be etched on the ground edge of each plate indicating the thicker side and pointing to the "good" faces. These faces should be silvered or platinized to a thickness which will transmit approximately 40% of the incident light.

Any glass filter used should likewise be very slightly wedge-shaped, truly parallel etalon or filter plates will display their own inherent fringe system, which will cause confusion in adjustment and in the interpretation of results.

Separators of the type used in the Allegheny instruments are quite easy to make. These consist of a bronze ring into which are forced three short pins of the best, tested invar. With file and oilstone these pins are first brought within about .0001 inch of the same length as measured with a micrometer, and the ends of the pins are somewhat rounded. The separator is then

In the conventional type of interferometer, the choice of the preliminary magnification given to the corona image is intimately connected with the separation adopted (the instrument SOUV, without preliminary magnification, will be described later). Without such magnification, the corona might fall entirely within the first interference ring.

The radii of the various interference rings in degrees, are given by the formula,—

$$R = 57.3\sqrt{n\lambda/e}$$

where n is the order of the ring, λ the wave length, and e the separation. The rings will almost invariably be of fractional order, as,—0.4, 1.4, 2.4, etc. The fractional part can not be predicted; for example, the smallest ring may even be of the order 1.2, as the fractional ring of order 0.2 would not show except in the sharpest lines. The magnification of the telescope system, in connection with the separation employed, should provide that one or more rings will fall on the brighter parts of the coronal image. The larger separations have the advantage here, as they not only produce sharper rings, but a larger number of rings in the area involved. While rings of such higher orders of interference are less bright, the theoretical loss from this is small.

In Table 2 are given the radii of the rings which would be obtained with the various instruments at the chosen wave lengths, together with the magnifications and separations employed, assuming, for convenience, that the fractional order is 0.4. Bearing in mind the fact that we may expect some coronal effect over a zone about $0^{\circ}.1 \times$ magnification in width it will be seen from Table 2 that there was a reasonable certainty in each case that least one interference ring would fall upon the coronal area. The least favorable case is AOG at Benkoelen, with an etalon separator of but 1 mm. In this case, however, more by accident than design, the coronal image was displaced from the center of the ring system, so that at least one ring must have been operative. As detailed below, the coronal image was purposely placed off center in SOUV.

Following the eclipse of 1926, the suggestion was made by Wright that the coronal radiation at 3388A might be superior to that at 5303A, because of the decreased intensity of the general scattered radiation in

placed between the etalon plates and the whole laid on a plate of glass through which passes the light from a mercury lamp reflected from a diagonal mirror beneath. By exerting some pressure on each of the pins one can quickly locate the pins which are too long through the appearance of the interference rings. The longer pins are honed down by very light touches with a hard, fine oil stone, with repeated testings, until a round and well-centered ring system is obtained under very light and uniform pressure of the plates on the separator.

the ultraviolet compared with that in the green. He also suggested dispensing entirely with the preliminary magnification system as a compensation for the probably lower intensity (photographically) of the ultraviolet coronal line. In order to be sure that the corresponding smaller and unmagnified image would be crossed by interference rings in the interferometer SOUV, he left the center of the interference system on

TABLE 2

Instrument	SOG	SOUV	AOG	AOG	AOG	AOUV
Place and date	Yerbaniz, '23 New Haven, '25 Benkoelen, '26	Takengon 1929	New Haven 1925	Benkoelen 1926	Takengon 1929	Takengon 1929
Line	5303A	3388A	5303A	5303A	5303A	3388A
Magnification	4×	1×	6×	6×	6×	4×
Etalon	2.5 mm	2.5 mm	3.75 mm	1.0 mm	6.5 mm	5.0 mm
Sun's radius ×magnif.	1°.06	0°.26	1°.62	1°.63	1°.58	1°.06
Order of rings			Radii of rings			
0.4	0°.53	0°.42	0°.43	0°.83	0°.33	0°.30
1.4	.98	.79	.80	1 .56	....	.56
2.4	1 .30	1 .04	1 .06	2 .05	....	.74
3.4	1 .53	1 .24	1 .25	2 .43	....	.88
4.4	1 .75	1 .41	1 .43	....	....	1 .00
5.4	1 .94	1 .57	1 .58	....	....	1 .11
6.4	2 .11	1 .71	1 .72	....	1 .31	1 .21
7.4	2 .27	1 .83	1 .85	....	1 .41	1 .30
8.4	....	1 .95	....	....	1 .50	1 .38
9.4	....	....	....	....	1 .59	....
10.4	....	....	....	....	1 .67	....
11.4	....	....	....	....	1 .75	....

the optical axis, but displaced the coronal image radially so that it would be crossed near the solar equator by the ring of fourth order. The direction of this displacement was so chosen that the polar axis of the sun's image lay radially on the interference pattern. The two portions of any ring would then intersect the corona at the same solar latitude, and a comparison of their radii should give the Doppler effect for that latitude.

III. ISOLATION OF THE DESIRED CORONAL RADIATION

The successful use of the interferometer demands a monochromatic light source. The corona is, of course, far from monochromatc, so that its light must be subjected to some preliminary sorting before entering the interferometer. This has been attempted in two ways,—by filters, and by filters plus prismatic dispersion. The various attempts of the

authors to solve the difficult problem of adequate monochromatization are summarized in Table 3.

The degree of isolation required is unknown. It was at first thought that the radiation at 5303A was sufficiently intense in comparison with the continuous background so that a suitable filter would cut out enough of the continous spectrum to leave the 5303A radiation predom-

TABLE 3. *Exposure and filter data*

Eclipse and duration	Instrument and order	Filter	Plate	Exposures
Yerbaniz	SOG	Min. blue	East. spec.	120 sec
1923 190 sec	10,000		green	50 sec
New Haven	SOG	Min. blue	East. spec.	120 sec
1925 124 sec	10,000	+prism	green	
	AOG	Min. blue	Pinaverdol	120 sec
	14,300	+prism	stained	
Benkoelen	SOG	Min. blue	East. spec.	180 sec
1926 190 sec	10,000	+prism	green	
	AOG	Min. blue	Pinaverdol	180 sec
	3,800	+prism	stained	
Takengon	SOUV	G986A+	East. 40	240 sec
1929 298 sec	14,800	$NiSO_4$.Qq.		40 sec
	AOG	Merc. green	East. 33+	280 sec
	24,500	+prism	pinaverdol	
	AOUV	UG 1	East. 33	280 sec
	30,000			

inant. No such filter has been found; in fact, it probably does not exist, for the transmitted 5303A light must be predominant over the integrated effect of all the other wave lengths which are transmitted. In general, the wave length of maximum transmission will not agree with that desired, and the width of the transmitted band will be several hundred AU. When filters are found with narrower regions of transmission, the maximum light transmitted is usually less than twenty percent, so that relatively there is little gain from the sharper filter, especially when the maximum does not fall in the precise region of observation.

There is, however, the possibility that such filters of narrower range may very definitely improve the contrast on the photographic plate, by cutting out relatively more of the continuous spectrum. Contrast on the photographic negative depends upon so many factors, subjective and objective, that any precise calculation or prediction is impossible, and the matter can only be settled empirically. It was felt that a definite improvement had been made by substituting a Mercury Green filter

in AOG in 1929 for the Minus Blue filter employed earlier. The Mercury Green does not transmit as much light at 5303A as the Minus Blue, but its transmission limits are much narrower. It thus cuts out a very large amount of yellow light which passes through the Minus Blue, which operates to mask any interference which might occur. The substitution produced a plate which seemed much more "monochromatic" than with the Minus Blue, and almost without the former very annoying streaks of strong continuous spectrum.

All our later attempts to record coronal interference in the green region have employed the objective prism plus a filter. The relative intensity of 3388A and its continuous background may be somewhat more favorable than in the green region. The two ultraviolet interferometers, SOUV, and AOUV were both direct, i. e., did not employ an objective prism for additional monochromatization, but the efforts to isolate 3388A with filters only in 1929 were unsuccessful. The use of an objective prism in the ultraviolet, perhaps with filters of less density than before, is a line of attack for the future with, however, no very great chance of success.

With the use of the objective prism, aside from absorption in the prism and reflection losses at the extra surfaces which are introduced, no changes in the intensities of the coronal images due to 5303A or 3388A should be expected from the dispersion. The overlapping of these images with the background is dependent upon the dispersion employed and upon the angular width of the annular coronal image. Since well-resolved coronal images can be obtained with an objective grating in the light of 5303A, there would seem to be no reason why these could not be duplicated with the proper prismatic train. Even with the superior intensity of a prismatic image, the question of success depends entirely upon the existence of enough light of the selected wave length to form images when the etalon is inserted. The use of large aperture etalons in connection with Wright's method of dispensing with the preliminary magnification system would obviate this difficulty to some extent, but introduces the necessity for large objective prisms if there is to be much angular magnification of the coronal interference pattern.

The overlapping of colors with prismatic dispersion will not be the same at all parts of the annular images, being much less along a radial strip which is parallel to the plane of dispersion than along a radial strip at right angles to the dispersion. Since the Doppler effect is to be looked for at the equator of the coronal image, the dispersion should preferably

be parallel to the sun's equatorial diameter. This condition, coupled with the angle introduced in the optical axis of the system by the objective prism, greatly complicates the mounting of such an interferometer on a polar axis. Some may prefer to mount the system upon a pier and use a coelostat; this means, however, an additional loss of light in a problem where the smallest losses are serious and to be avoided in any way pos-

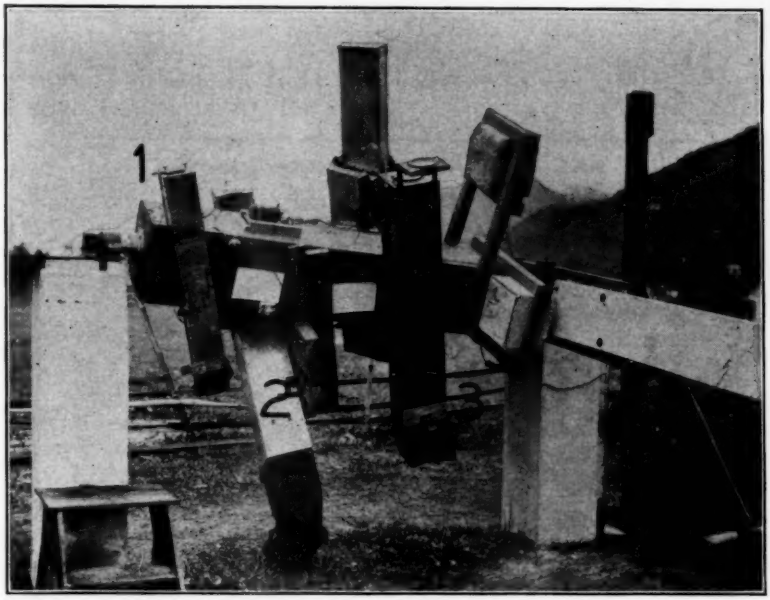

FIG. 1. *Interferometers mounted on polar axis at Takengon.*

1. *Interferometer for the line 3388A. SOUV.*
2. *Interferometer for the line 5303A, AOG.*
3. *Interferometer for the line 3388A, AOUV.*

An infrared grating spectrograph, unnumbered, is mounted on the farther side of the axis.

sible. It may be mentioned here that, by the use of suitable concrete blocks as counterpoises, but slight difficulty was experienced in mounting the long and heavy AOG objective prism interferometer "across" the polar axis at Takengon, so as to make the dispersion parallel to the sun's equatorial diameter. See Fig. 1, showing the instruments as mounted at Takengon.

IV. DETAILED DESCRIPTION OF INSTRUMENTS AND RESULTS

A. INTERFEROMETERS WITH PRELIMINARY CORONAL MAGNIFICATION

1. *The Sproul Observatory Green Interferometer*, SOG. This was the first of the interferometers to be made, and was constructed by Wright for the 1923 eclipse; with the addition of an objective prism, it was employed also at the eclipses of 1925 and 1926. The optical arrangements are shown schematically in Fig. 3.

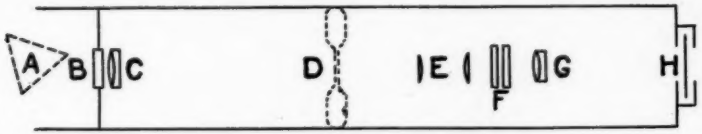

FIG. 2. *The Sproul Observatory green interferometer, SOG.*

A, is a 60° prism of light flint glass, used in 1925 and 1926.
B, the Minus Blue Wratten filter.
C, a two-piece objective, aperture 5 cm, focal length 40 cm.
D, a neon tube that was inserted in the focal plane of C when forming the comparison interference rings.
E, a Ramsden eyepiece, focal length 10 cm.
F, the etalon.
G, a two-piece objective, aperture 2 cm, focal length 25 cm.
H, the plate-holder, taking 3 1/4×4 1/4 inch plates.

The etalon was of glass, with a 2.5 mm separator of fused quartz. This gave an interference order of 10,000 and a resolving power of about 200,000, on the assumption that the ring diameters could be measured to one part in twenty. The corresponding linear velocity of rotation obtainable would be 1.5 km/sec, a quantity about one-half as large as Campbell's estimate from spectrographic observations.

The comparison system was obtained by inserting a neon tube at the focus of the objective. Its capillary was sharply focused on the plate and comparison exposures were made with the tube in two positions, crossing centrally at right angles. Care was taken to have these reference lines cross the coronal image at latitudes $\pm 45°$, thus leaving the polar and equatorial regions free from extraneous light. The capillary was bright enough so that exposures of ten seconds gave sharp segments of the interference rings due to both 5852A and 5944A. Eastman Special Green Astronomical Plates were used, and two exposures, 120 sec and 50 sec in length were secured in 1923. Each plate gave a dense coronal image which showed no evidences of an interference pattern. The negatives were afterwards reduced with ferricyanide, but were still free from recognizable interference effects.

After an objective prism had been added, this interferometer was employed at New Haven in 1925. The instrument was oriented so as to make the dispersion produced by the prism perpendicular to the sun's axis, giving minimum overlapping at the equatorial zone. One plate was secured with an exposure of two minutes. The image of the corona was much less dense than before and, of course, fuzzy due to the dispersion. Again no recognizable traces of an interference pattern could be found.

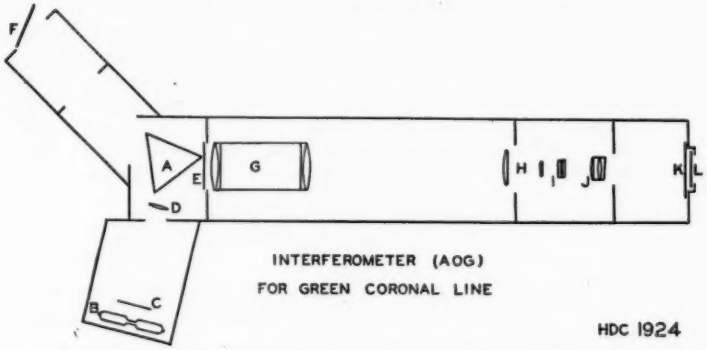

FIG. 3. *The Allegheny Observatory green interferometer, AOG.*

A, is an excellent light flint glass prism of 60° angle and 11.5 cm on a face, made originally for Langley. Deviation 44° 43′ for 5303A.

B, the helium comparison tube; C, a ground glass screen; D, the comparison lens of 25 cm focal length, sending parallel light through the system by reflection from the rear prism face.

E, a frame which can be removed at will, holding a gelatine filter 10 cm square.

F, the hinged aluminum exposure window.

G, a four-piece doublet, aperture 10 cm, focal length 53 cm, giving, with the large ocular, H, a magnification of about 6×.

I, the etalon and holder.

J, a Cooke-Taylor camera lens of 5 cm aperture and 21 cm focal length.

K, a brass comparison diaphragm plate, pierced by two slots at right angles making an angle of 45° with the dispersion; each slot is about 0.6 mm wide and 8 cm long. This diaphragm is moved to one side for the eclipse exposure; it is, in addition, so mounted on slides that it can be adjusted by means of knurled head screws (not shown), in connection with similar means of adjustment on the etalon holder and its slide, so that the cross formed by the two slits can be accurately centered with the interference ring system.

L, the plate-holder, taking 3 1/4×4 1/4 inch plates.

2. *The Allegheny Observatory Green Interferometer*, AOG. This instrument, shown schematically in Fig. 3, was built of light brass angles and aluminum sheet 2.5 mm thick. The main portion is 122×23×20 cm, not including the two angular attachments for the light cap and the comparison apparatus.

3. *The Allegheny Observatory Ultraviolet Interferometer*, AOUV. It seemed adivisable to try both types of interferometers, i. e., with and without preliminary magnification of the image, in the ultraviolet region at the 1929 eclipse; this instrument was accordingly constructed by Curtis at Dr. Miller's suggestion. The box is built of 16-gauge brass (1.3 mm thick), and is 122×20×20 cm in size. See the diagram, Fig. 4.

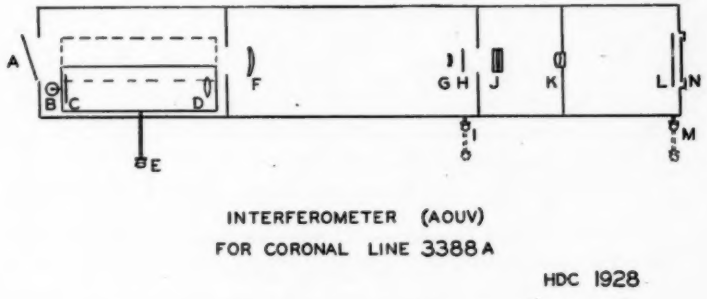

FIG. 4. *The Allegheny Observatory ultraviolet interferometer, AOUV.*

A, is the hinged exposing cap.

B, C, and D, respectively, are the helium comparison tube, the ground glass diffusing screen, and a comparison lens of 25 cm focal length. This comparison system is mounted as a unit on guides so that it can be pulled to one side of the optical axis by the handle, E.

F, and G, are the two lenses of fused quartz forming the telescopic magnification system. These are respectively 5 cm and 2.5 cm in aperture, and 30 cm and 7.5 cm focal lengths, giving a magnification factor of 4. They were made by Fecker, and are of meniscus form to minimize some of the aberrations.

H, is the UG 1 glass filter, about 3 cm in diameter and 2 mm thick, mounted on ways so that it can be pulled to one side of the optical axis by means of the handle, I.

J, is the etalon, of fused quartz, and its cell.

K, is a quartz-fluorite lens of 2.5 cm aperture and 25 cm focal length, which gives a flat field from 2,000A to 8,000A.

L, a diaphragm plate with crossed slits as in AOG, removable by the handle, M, and provided with centering adjustments.

N, the plate-holder, for 3 1/4×4 1/4 inch plates.

The accumulated experience of the first trials made it advisable to add many small conveniences, not described here, in the interest of greater speed in adjustment. The etalons of both instruments could be easily removed on their dove-tail slides for adjustment and test; light-tight doors in the side walls were provided for this and for other necessary focal alterations, etc. These instruments were fastened to the polar axis by iron angles with slots for adjustment. The strong wooden frame on which AOG was mounted so as to make the dispersion parallel to the

sun's equator was also provided with a threaded steel rod brace with a turn-buckle for adjustment in declination.

The program of observation was essentially the same each time these two instruments were used, and was planned so as to secure three sets of interference rings of different wave lengths in addition to the crossed-slit sections of rings imprinted on the eclipse plate. The procedure may be illustrated by the observing program for AOG at Takengon in 1929.

Plate I. Eastman 33, stained with pinaverdol. With filter out and slit-diaphragm in, expose comparison from the call "15 minutes before" to the call, "5 minutes before." Side filter in, and pull slit-diaphragm out. Expose from immediately after the first flash till the count of 280 sec. Hg Green filter used. After totality, pull out filter, push in slit plate, and expose 10 min. more on the comparison. The plate-holder slide was, of course, not touched in this interval.

Plate II. After the eclipse. Eastman 40. 10 min., without filter or slit.

Plate III. After the eclipse. Eastman 33, stained with pinaverdol. 15 min., without filter or slit.

Plate IV. After the eclipse. Change to Minus Blue filter. Eastman 33, stained with neocyanin. 15 min. with this filter, but with slit plate out.

The comparison spectrum of AOUV was found very rapid, 2 min. being ample for strong rings on a pinaverdol stained plate. AOG suffered from the disadvantage of loss of light in the comparisons through the reflection at the rear prism face, and comparison exposures of 15 to 30 min. were necessary. The auxiliary plates taken at each of the eclipses have indicated that the interferometers were in excellent adjustment; in fact, the etalons showed a permanency scarcely to be expected in an interferometer used under field condition. The etalon for AOG needed, and received, no adjustment for 14 days preceding the eclipse at Takengon. At each eclipse the final inspection of the etalons and adjustments in general was made in the early morning preceding the eclipse, as this can best be done at night.

The results from the AOG plates are entirely negative. At New Haven, in 1925, the plate shows very strong streaks on each side of the lunar disk, due to the continuous spectrum. There is no trace of interference.

The plate taken in 1926 at Benkoelen is stronger, though, because of tropical conditions, the staining is not so clear. In addition to very strong streaks of continuous spectrum, this plate shows three small patches of short, fairly strong, interference like fringes, and at first it was thought that the problem had been successfully solved. One of these patches of fringes, however, encroaches on the lunar disk, and careful measurement of all has shown that they can not possibly be due to inter-

ference effects. We have been unable to find any explanation for these curious fringes on this plate, and can only suggest that they may be due in some as yet unknown way to reflections within the instrument. Aside from these appearances, there is no certain evidence of coronal interference.

At Takengon, in 1929, due to the hot climate, the pinaverdol staining for the AOG plate is again less clear and clean than that at New Haven. Because of the change to the Hg Green filter, the coronal ring, while broad and indistinct, is stronger around nearly the entire circumference, and the background of the continuous spectrum streaks is far fainter and less troublesome than in the earlier trials using the Minus Blue filter. Burns and Curtis, after repeated careful examination, believe that there is evidence of interference in the corona on this plate, but that the effects are so exceedingly faint that there is danger that it may be subjective instead of objective. This evidence is so near the limit of visibility that it would be unwise to state it as a reality; certainly these appearances would be absolutely impossible to measure. Sections of rings to at least the 100th order are shown in the slit comparisons on this plate; as the exposure on this plate was 280 seconds, it perhaps marks the limit of attack on this problem by apparatus of the types constructed to date.

Because of its extreme rapidity, some measure of success was confidently hoped for with the Quartz AOUV interferometer. The comparisons are excellent, but only the merest trace of a coronal ring is visible, and there is no evidence of any interference.

B. INTERFEROMETER WITHOUT PRELIMINARY CORONAL MAGNIFICATION

. *The Sproul Observatory Ultraviolet Interferometer*, SOUV. A general statement of the considerations which led Wright to the design of this type has been given. It apparently possesses very marked advantages in its freedom from the losses of light due to the preliminary telescopic magnification system of the conventional type of instrument, and seems likely to be the most advantageous starting point for future attacks on the problem. This instrument was constructed by Wright for the 1929 eclipse, and manipulated by Curtis at the eclipse. The details of the instrument are shown in the diagram, Fig. 5.

There is no preliminary magnification, and the size of the resulting coronal image is controlled by the focal length of the camera lens. This lens and the etalon were mounted on a carriage which slid in ways to allow the focus to be changed to varying settings for sharp registration

of the coronal ring at 3388A, or the comparison fringes due to 3889A, 4471A, and 5875A. The total shift in focus between 3388A and 5875A was 1.8 cm, and was controlled by a rack and pinion with an external milled head.

FIG. 5. *The Sproul Observatory ultraviolet interferometer, SOUV.*

A, is the filter cell, so mounted as to be removable from the train.
B, the etalon.
C, a quartz meniscus lens, aperture 2 cm, focal length 50 cm.
D, the screen with slots and circular aperture.
E, the plate-holder, for plates 3 1/4×4 1/4 inches in size.
F, a helium tube mounted in the train in the focal plane of G when making the comparison rings.
G, a quartz lens of 25 cm focal length, which replaced the filter cell A when F was used.

The photographic plate was screened with a brass plate having two slots milled in it, crossing centrally at right angles. In one quadrant of this plate a small circular opening was provided, lying about 1° from the optical axis, and fitted with a small shutter flap, which protected the plate during the exposures to the helium comparison, and which was opened when the exposure was made on the corona.

The filter consisted of 3 mm of G986A glass, together with 1 cm of nickel sulphate solution. The latter was adjusted in concentration so that the combined filter transmitted from ten to fifteen percent of the mercury line 3341A, and less than one percent of 3650A. Due to an unfortunate accident in transit, this particular solution was lost and replaced with one made up on the field. The transmission of the actual filter used at Takengon is thus unknown.

For obtaining the comparison rings, the filter cell had to be removed and replaced by a second quartz lens of 25 cm focal length. At its anterior focus was placed a helium tube with a diffusing filter of G586 glass for transmitting 3889A. The tube was also fitted with gelatine filters for 4471A and 5875A. Exposures to these latter radiations gave the necessary data for standardizing the etalon.

This instrument, so far as known the first of its particular type, suffered from a number of drawbacks and serious risks of error in use under field conditions. The replacement of the filter with the comparison lens,

and the necessary change of focus between the coronal exposure and that of the comparison system impressed on the eclipse plate, necessitated opening the instrument for the transfer and for making the change in the focal setting. During these changes, the slide of the plate-holder had to be pushed in, to be withdrawn later for the eclipse exposure. Though every precaution was taken to clamp the plate-holder firmly, this was regarded as a rather dangerous procedure. It would be quite possible to obviate this risk in remodeling the instrument for another attempt, by providing an external focusing scale and transverse slides for the exchange of filter and comparison lens manipulated by handles through light-tight glands as in AOUV. Still better would be the employment of a quartz-fluorite lens to do away with the necessity for focal changes, though it is admittedly very difficult to secure such lenses of adequate size.

Two exposures were made on the corona at Takengon with SOUV, on Eastman 40 plates, one of 240 seconds and the other of 40 seconds. Both plates show a well developed coronal image extending outward about three minutes from the edge of the moon's disk. The image is not uniformly dense, but the irregular distribution of the denser portions does not correspond to any interference pattern.

V. RESUMÈ OF THE EXPERIMENT

A priori, the problem of registering coronal interference has many of the characteristics of a forlorn hope. At best, and in eclipses of maximum duration, the lines of the coronal spectrum are faint, and not easy to record in the higher dispersions. It is perhaps too much to expect that these faint sources, in the limited duration of a total solar eclipse, can be so separated from the powerful accompanying light as to leave a legible record after passing through a further dispersion mechanism so wasteful of light as an interferometer. We have now attempted to secure interference in the stronger coronal radiations at four eclipses. Wright, who initiated the investigation, has tried it three times at 5303A, and once at 3388A with a new type of interferometer without preliminary coronal magnification. Curtis has likewise tried it three times at 5303A and once at 3388A, varying the order of interference from 3,800 to 30,000.

With one quite doubtful exception, the results have been uniformly negative. It would be quite possible to deduce from this summary the general conclusion that the experiment is finished with a negative result, and that success is impossible with present apparatus. This leads natu-

rally to a brief discussion of the possibility of modifying existing apparatus, or improving the method.

VI. SUGGESTIONS FOR FUTURE TRIALS

1. Further experiments with filters may well be desired but the most promising means of cutting out the powerful continuous background appears to lie in the use of objective prisms. The combination of a filter with the prism may be superior to the prism alone but there seems little likelihood of finding a filter which will be sufficient by itself.

2. There being no conclusive evidence to the contrary, preference should be given to the line at 5303A. Adjustments in optical trains are hard to check in the field, especially in those containing prisms. The possibility of making these visually would be lost if 3388A were chosen.

3. The low optical efficiency of the etalon presents one of the major obstacles. High transmission and sharp interference maxima are mutually exclusive. The etalon plates in our work have been silvered to give about 40% transmission through a single film at normal incidence. The rings formed by such an etalon have a maximum intensity of about one fifth of the average intensity existing in the same focal plane when the etalon is removed from the train. This loss of light is serious and unavoidable. It is to be remembered, however, that satisfactory monochromatic coronal images have been obtained with large objective gratings which suffer from the same defect and the obvious remedy lies in the use of larger etalons.

4. Our interferometers of the conventional type with preliminary magnification have hitherto had their effective aperture ratios in the range from f:60 to f:100. By omitting the magnification system and by using larger etalons, lenses and prisms, it should be possible to increase the speed, if desired, by a factor of from ten to twenty. Etalon plates 10 cm in diameter and plane to 1/20 wave are feasible. The speed would then be dependent on the focal length of the camera lens and, in deciding upon this, a proper balance would have to be struck between optical speed and image size. The authors favor a ratio of 1:20; this focal ratio with ten centimeter plates would call for a focal length of 200 cm and would give a coronal image about 2 cm in diameter. This relatively large scale image would offer great advantages in the measurement of details in the coronal structure.

5. Mechanical provision should be made so that all alterations of filter, focus or comparison system may be made without opening the instrument, thus obviating any need for touching the plate holder in any way

during its exposure to the corona and to the comparison source. It is advisable to shield the plate during the comparison exposure with a removable occulting disc one degree in diameter, thus securing complete interference rings over the entire plate except where the coronal image falls. This set of rings on the plate itself together with the ring systems on the auxiliary plates will suffice to calibrate the optical system completely.

6. As we are ignorant of the atomic mass of the source of the corona lines, suggestions as to the orders of interference to be used are mere guesses. Separations of less than 2.5 mm will not afford sufficient resolving power to measure a Doppler effect of the expected magnitude. Separations as large as 5 mm are probably allowable and the use of even larger separations is not contradicted by the success in recording the stronger coronal lines with high prismatic dispersion. The larger separations afford the manifest advantage that a greater number of fringes will cross the coronal area involved.

OPTICAL PROPERTIES OF A LIPPMANN LENTICULATED SHEET

By Herbert E. Ives

[Bell Telephone Laboratories, New York, N. Y. Received Jan. 13, 1931]

In 1908 Professor G. Lippmann suggested a novel method for making photographs without the use of a camera—pictures which should, moreover, change their appearance with the position of the observer, and so show stereoscopic relief from all directions and distances. The special means proposed consisted of a sheet of transparent material embossed with a multitude of small convex lenses, each of which formed a minute picture upon the photographic emulsion on the rear surface. When such a sheet is held before the eye a composite or *integral* image, as Lippmann called it, is seen, a single tiny element of each minute picture being seen from any given position, and since the elements seen change with the position of the eye, the character of the integral picture changes as the observer moves. *If the minute pictures are properly oriented and positioned* one should see a virtual re-creation of the object in space. This idea of Lippmann, while never reduced to practical form, has been generally conceded to constitute an ideal solution of the problem of securing stereoscopic vision without a stereoscope.

Lippmann proposed two methods of making photographic positive pictures, using the lenticulated sheet. The first method consisted in carrying through a purely photographic reversal, that is, the original negative was reversed by dissolving out the developed image and reexposing, and was thus ready for observing from the side which faced the object. The second method consisted in setting up another (unexposed) lenticulated sheet at some convenient distance from the original negative, and exposing it to the light transmitted through the latter. This second method produced a geometrical as well as a photographic reversal.

Now it is abundantly clear from Lippmann's several descriptions of his idea, and from his accounts of attempts to demonstrate the principle, that he believed these two methods to be equivalent, that is, that a true relief picture could be obtained by either procedure. As is shown below, this is not so. The originally exposed lenticulated sheet exhibits reversed or pseudoscopic relief; the procedure involving rephotography is not merely an alternative method, it is imperative, if a true relief picture is to be obtained.

The occurrence of pseudoscopic relief, where stereoscopic relief is

sought is the *bête noire* of relief picture schemes and demands meticulous care in tracing the paths of light rays, and in analyzing the behavior of the image. Its occurrence frequently demands the introduction of some special inverting procedure. One illustration of such a procedure is the operation of cutting in two the print from an ordinary stereoscope negative, obtained with a twin lens camera, and transposing the two pictures. Another illustration is the parallax panoramagram as made with a large lens or mirror, where to secure true relief it is necessary to mount the picture in front of the grating, instead of behind, as with other forms.

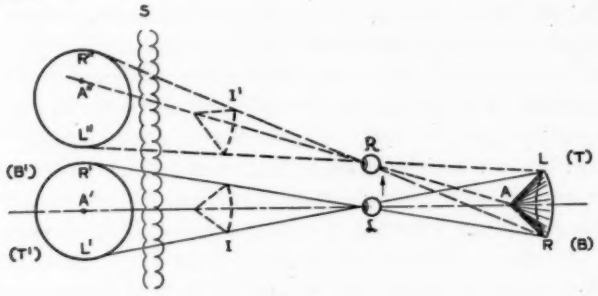

FIG. 1.

In order to determine whether an image is stereoscopic or pseudoscopic the sufficient criterion is as follows: If moving the eye laterally to the $\binom{\text{right}}{\text{left}}$ exposes more of the $\binom{\text{right}}{\text{left}}$ hand side of the image, relief is stereoscopic. If moving the eye laterally to the $\binom{\text{right}}{\text{left}}$ exposes more of the $\binom{\text{left}}{\text{right}}$ hand side of the image, relief is inverted or pseudoscopic. In this connection it is to be noted that no inversion of the image as a whole, that is, its orientation as referred, for instance, to the original object, makes any difference, any more than turning the original object upside down or viewing it in a mirror alters the nature of the relief it exhibits. *All that is in question is the right and left side of the image as seen.*

With this criterion in mind, let us examine the case given by Lippmann in Fig. 2 of his original paper.[1] This is reproduced in considerably amplified form in our Fig. 1. Here S represents the lenticulated screen in section, $\mathcal{R}$ and $\mathcal{L}$ represent positions of the observer's eye, looking toward S, while at L, R is shown the original object to which the screen S has been exposed. The object we represent as a cone whose apex A points toward the screen. If, following Lippmann, we produce rays

[1] Comptes Rendus, *146*, 446–451; 1908.

from the object through the eye at $\mathcal{L}$ to the screen, we obtain a projection R', L', of the cone, which shows what the eye would see on looking at the screen, since the screen merely returns these rays back on their original paths toward the object. As drawn, the apex of the cone, A, lies in the center of the circle which is the projection of the base. Let us now move the eye to $\mathcal{R}$, that is to the right, as this is a plan view. On producing the rays from the object through the eye as before we obtain the projection $R''L''$. Disregarding for the present, all questions of position and movement of the image as a whole, we see, on applying our test, that the apex of the cone has moved toward the *right* hand side

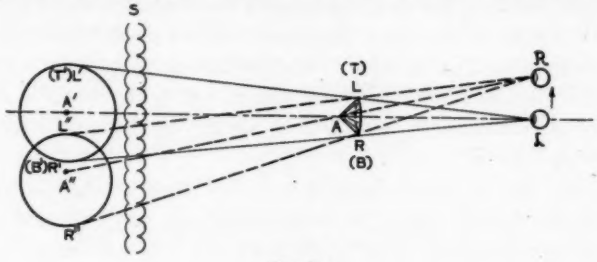

FIG. 2.

of the image, that is more of the *left* hand side is exposed by moving the eye to the *right*. Thus the image in *pseudoscopic*. The cone is seen in fact with its apex pointed away from the observer as indicated by the dotted figures I and I'.

There is a second case not considered by Lippmann, namely, where the original object lay in the space between the eyes and the screen. This is shown in Fig. 2. Performing the same projections as before, we find again that as the eye moves to the right, the apex of the cone also moves to the right with respect to the base, covering part of the right hand side of the image. The image is *pseudoscopic* as before. This image is, however, quite different from that of Fig. 1 in its behavior in other respects which now deserve attention. We must look into the matter of the orientation of the image, its position in space, and its movement, comparing these characteristics with those of the object.

Consider first, the question of the orientation of the image. As already noted, this has no effect on the character of the relief; it is, however, a fundamental characteristic of an image and must be properly taken care of if a faithful picture is desired. Let us consider, (as the only possible convention) that the orientation of the original object is de-

cided by viewing it *from the screen*, and that the orientation of the image is decided by looking *toward the screen*. Referring now to the plan view in Fig. 1, L and R represent the right and left hand sides of the object viewed as above, R' and L' the projection of the same sides. From the observing positions $\mathcal{R}$ and $\mathcal{L}$ it is found that the object is *correctly oriented laterally*, R' is at the right, L' at the left. If now we imagine for a moment that this figure is an elevation (T) and (B) give the top and bottom of the object, and (T') and (B') the corresponding points on the image. We see that the *image is inverted top for bottom.*

Transferring our attention to the case shown in Fig. 2, we find by the same analysis that the image is *inverted right and left*, but *right side up*. The orientation of the image therefore changes according as the original object was behind or in front of the position subsequently occupied by the eye. The behavior recalls the way in which the image formed in a concave mirror changes from real to virtual as the object passes thru the principal focus.

We have not, however, finished with our study of the images formed in these two cases. Case 2, it is true, presents no peculiarities beyond those already disclosed. The image is similar to a real image, it remains fixed in space as the eye moves, and the two eyes converge in a normal manner to view it. (The image is, in fact, a *transparent* re-creation of the object.) The situation is quite different with respect to the case shown in Fig. 1. If we attempt to locate the image we observe that the two eyes must be *diverged* to pick up the corresponding images, that is, the object, if it can be considered as located in space at all, is behind the head! A second peculiarity obtrudes itself upon our attention. As the eye is moved to the right the projected rays show that the whole image moves in the same direction. Its motion is, in fact, as though the object were the fulcrum, the eyes the force, and the image the weight, of a lever of the third class. Thus the movement of the image is quite unnatural, the whole image simulates in its movement the apparent shift of objects beyond the convergence point of the eyes. In the case shown in Fig. 2, the image behaves normally in this respect, standing stationary in space as the eyes (converged upon it) move, the only apparent motion then being that of the screen itself, in the direction of the motion of the eyes.

Let us now summarize the characteristics of the images exhibited by the screen in the two cases.

Case I. (Eye between screen and original position of object.)

Image is pseudoscopic.
Image is inverted top for bottom.
Image is observed with the axes of the eyes diverging.
Image moves in the direction of motion of the eyes.

Case II. (Original object between eye and screen.)

Image is pseudoscopic.
Image is inverted right and left.
Image is observed with the axes of the eye converging.
Image is stationary in space.

It is now pertinent to ask how it happens that the true nature of the images rendered by this structure has not been made clear before. As mentioned above, the Lippmann screen has never been reduced to practical form. In a second paper[2] Lippmann describes a crude test of the screen made with a number of glass rods with spherical ends. He obtained an image in space in natural size which remained fixed when the screen was moved parallel to itself, and which followed the movements of the eye when the screen was stationary. In a still later paper[3] he describes a test of the method made with 12 small lenses mounted in a rectangular frame. A negative was made, developed, reversed, and put back in its original position behind the lenses. On looking at the lenses he obtained a unique image projected in space, and different for the two eyes, "Ce qui donne l'impression du relief." He verified that if the observer moved he saw new parts of the image. Now by consulting the above summary, it is seen that all of these observations can be true, but they do not prove that the image is stereoscopic. The real criterion for the character of the relief was not applied, either in the development of the theory, or in the experimental test. Detoeuf[4] does call attention to the divergence of the eyes demanded by the use of the original negative, as constituting a difference between the direct image and the photograph, but fails to note the pseudoscopic character of the image.

It is of interest to point out that a form of the Lippmann negative as photographically reversed, or a contact print from it, can be so viewed as to exhibit true stereoscopic relief. The essential variation on the method of viewing proposed by Lippmann is that observation should be made *through* the photographic layer toward the position of the original object, that is, the same expedient should be adopted as

[2] J. de Physique (4) 7, 821–825; 1908.
[3] Societe Francaise de Physique, Procès Verbaux, 1911 p. 69.
[4] La Nature, *36*, pt 1, 252–254; 1908.

with parallax panoramagrams made with a large lens.[5] The lenticulated sheet is not adapted to this method of observing, but if in its place we use a thin opaque sheet perforated with numerous pinholes, as shown in section at G. Fig. 3, the pinhole images formed on the photographic

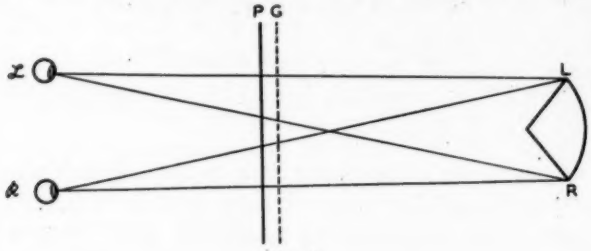

FIG. 3.

layer P will fuse to form a true stereoscopic image when the eyes are placed so as to look through P to G at a continuous background. This is obvious by inspection of the figure, for the viewing operation is exactly like looking at the original object through the perforated sheet.[6]

In conclusion it is proper to emphasize that the method of making copies suggested by Lippmann, namely, setting up a second screen in front of the first at some distance and exposing without the interposition of any lens, is valid. For a pseudoscopic copy of a pseudoscopic picture, becomes, by virtue of the double reversal, a picture in correct relief. Or, putting it differently, the copy thus made is observed from the direction of the original screen, so that the light rays from the copy follow exactly the paths to the observer that the rays from the original object did.

[5] J.O.S.A., *20*, 332; 1930.

[6] Estanave has recently (Comptes Rendus, *24*, 1405; 1930) described a test of the Lippmann method using exactly this kind of perforated screen. He viewed the negative through the screen, but, contrary to the above findings, he reported a complete verification of the principle. The object photographed,—a bright lamp filament—could not have been worse for purposes of making a critical test, and none of his observations of movement of the image, etc., are in conflict with the above discussion.

FORMATION OF PHOTOGRAPHIC IMAGES ON CATHODES OF ALKALI METAL PHOTOELECTRIC CELLS

By A. R. Olpin and G. R. Stilwell

[Bell Telephone Laboratories, New York, N. Y. Received December 17, 1930]

ABSTRACT

A method of forming both negative and positive photographic images on the cathodes of potassium and sodium photoelectric cells in vacuum is described. These images are sharp and clear in every detail and can be permanently "fixed" by proper treatment. Among the materials which have been successfully used in treating the exposed surfaces to bring out these images are sulphur vapor, air, oxygen and hydrogen in the ratio of 9 to 1, hydrofluoric acid and bromine. During the time the image is forming, the photoelectric sensitivity of the illuminated portions decreases approximately 30 percent. After the image is fixed as a permanent record there is little difference between the sensitivity of the cathode area bearing the image and neighboring areas. Photographs of photoelectric cells are shown in which such photographic images are plainly visible.

In a recent paper by one of us,[1] a technique was described for treating alkali metal surfaces in evacuated photoelectric cells with dielectrics, such as sulphur, water vapor, organic dyes, etc., to enhance their sensitiveness to light, particularly to light of long wave lengths. Previously, similar methods had been described for sensitizing photographic plates to red and infrared light.[2] The results of these experiments suggest a close relationship between photoelectric and photographic phenomena. This apparent analogy is emphasized still more in certain cases where the sensitizing materials are the heavier halogens. In these cases the emission of photoelectrons excited by blue light is inhibited by the superimposition of red of infrared light,[3] strikingly suggestive or the destruction of latent images on photographic plates by infrared light. This phenomenon will be further described in a paper soon to appear.

A still further analogy is found in a new phenomenon which was discovered in the course of our study of the effects described in the previous paragraph. On numerous occasions, we noted either coloration or bleaching of the limited cathode areas on which images of the filament of the test lamp were focused. These were shown to be either negative or positive photographic records of the glowing filament. Now, by proper manipulation of the conditions involved, we are able to obtain

[1] A. R. Olpin, Phys. Rev. 2, *36*, 261; 1930.

[2] D. B. Neblette, "Photography, Its Principles and Practices," Chapter 7. D. Van Nostrand Co.; 1927.

[3] A. R. Olpin, Phys. Rev. 2, *36*, 376; 1930.

clear and detailed photographs of illuminated objects recorded on the cathodes of photoelectric cells.

As a rule, these photographic images first appear as negatives and may gradually fade out; but they can be permanently "fixed" and even "reversed" by subsequent treatment on the surface. In Fig. 1 is

FIG. 1.

shown a photoelectric cell, on the cathode of which is recorded a negative image; in Fig. 2 is a similar cell with a positive image.

The method of treating potassium or sodium photoelectric cells with dielectrics to enhance their photoelectric sensitivity, as referred to in the first paragraph, consists essentially of admitting very small amounts of the sensitizing materials to an illuminated surface of the

freshly distilled metal in successive steps until the photoelectric current as recorded by a galvanometer reaches a maximum.[4] If the quantity required to produce the maximum emission is exceeded, a film of the light sensitive metal may be distilled onto the surface to restore the cell to the most sensitive stage previously noted. Frequently, addition of this film produces a still more sensitive condition. The optimum response is apparently obtained when in the surface structure metal and dielectric are present in certain definite proportions.

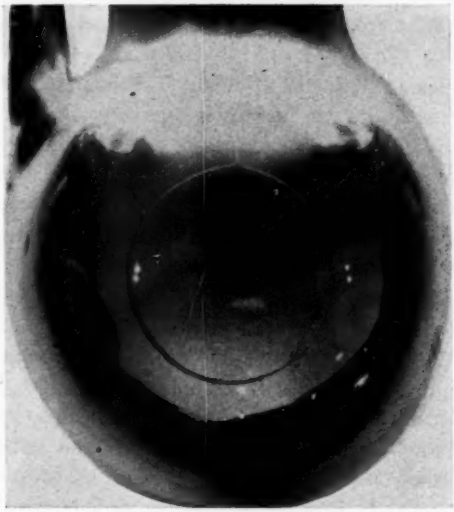

FIG. 2.

The formation of such a cathode surface in a photoelectric cell is a very critical process, and more frequently than not is imperfectly realized. In respect of the photoelectric effect, this is relatively less important, for the electron emission does not vary rapidly as the condition of maximum response is approached. In respect of the photographic effect, however, it is essential to have the surface properly constituted within very narrow limits, as otherwise there is no such effect at all.

When a part of the surface developed to the proper stage is exposed for a few seconds to a strong direct beam, it is visibly darkened, and

[4] See 1.

the photoelectric sensitivity falls off by some 30 percent. The colored portion may fade out in the course of a few days, but the photoelectric sensitiveness remains permanently changed. This photographic effect is most striking in sodium photoelectric cells treated with sulphur vapor and oxygen. (Incidentally, these cells yield perhaps more photoelectric current per lumen of incident light than any other similar cells, the amounts being of the order of 6. to 8. microamperes per lumen of unresolved light of color temperature 2848° K.) On one such cell, having a cathode area of approximately 30 square inches, rows of negative images of a glowing test lamp filament were made merely by focussing the light from the filament on successive areas for a few seconds each.

The difficulties and uncertainties involved in preparing photographically sensitive cathodes can be largely overcome by focusing an image of the object to be photographed on the cathode during the treatment with a suitable dielectric. If small amounts of the sensitizing material are now gradually applied to the cathode surface, the surface structure will eventually have the proper constitution for the photographic effect. This condition may exist only momentarily but the time is sufficient to produce a sharp negative photographic image of the object. Subsequent treatment serves merely to "fix" the image already formed. If, now, the light is left incident on the cathode while alternate films of the dielectric and the metal are deposited on the surface, it is possible to "reverse" completely the image making a positive out of a negative. After these "fixing" and "reversing" processes the cells still manifest marked photoelectric sensitivity. Moreover, the emission from the portion of the cathode bearing the photograph is very little, if any, less than that from other portions. Presumably, the image is now coated over with a transparent light sensitive film of the same material that constitutes the surface of the rest of the cathode.

Fig. 1 is a photograph of a negative image formed on the cathode of a potassium photoelectric cell which was sensitized by admitting a very small amount of hydrofluoric acid while the light was projected onto the metal coating. The optical system was simply a source of light behind a lantern slide with suitable lenses for focusing the transmitted light. As the gas entered the cell the potassium surface turned uniformly yellow except on those places where the light was focused, which turned a deep buff or brown. The quantity of gas admitted was slightly in excess of the minimum necessary to make the surface photographically responsive so that by the time the chemical action on the

surface was complete the image (*negative*) had not only been "developed," but had been permanently "fixed" as well.

The photoelectric cell shown in Fig. 2, bearing a *positive* image of a glowing test lamp filament, is also a potassium cell treated with hydrofluoric acid. We have chosen to show this cell because when the image was first formed on the cathode as the gas entered the cell, it was a *negative*, appearing blue-brown on a yellow background. Subsequently larger quantities of the same gas were introduced into the cell, interspersed with the deposition of thin potassium films on the cathode surface. All this time the light from the filament was focused on the spot where the first image appeared. Gradually a reversal took place, the cathode turning a dark blue and the image a light grey. The cell at this stage manifests almost the same photoelectric response as it did before the reversal occurred.

These photographs on the cathodes of photoelectric cells are surprisingly accurate in every detail. Every noticeable irregularity in the outline of the object roughly scraped on a blackened lantern slide glass is exactly reproduced in the image shown in Fig. 1. Moreover in Fig. 2 will be seen directly beneath the primary image and parallel to it, a very weak secondary image. This is a photograph of the test lamp filament as formed by reflection from the glass walls of the lamp bulb. It is actually much sharper and more prominent than appears from this illustration.

Both positive and negative images have been made on the cathodes of potassium and sodium photoelectric cells. Among the materials successfully used to bring out these images are sulphur vapor, air, oxygen and hydrogen in the ratio of 9 to 1, hydrofluoric acid and bromine. Undoubtedly the effect is photochemical, but the great variety of materials which can be used complicates the chemistry of the phenomenon. Recently there has appeared a note in *Nature* by C. J. Smithells[5] of the Research Laboratories of the General Electric Company at Wembley, in which he reported a method of obtaining photographic images on copper plates coated with a thin film of light sensitive cuprous chloride. These plates turn black on exposure to intense light *in air* supposedly because of a "conversion of cuprous chloride into cuprous oxide." Undoubtedly, some similar reaction takes place in the case of the alkali metal cells, the chief difference being that our photographs on the cathodes of these cells were made under *vacuum* conditions.

[5] C. J. Smithells, Nature *126*, 3169, 133; 1930.

A PLANE-PARALLEL PLATE REFRACTOMETER

By A. H. Pfund

[Johns Hopkins University, Rowland Hall, Baltimore, Maryland.
Received December 6, 1930]

The instrument about to be described is so elementary in principle and so simple in construction that its novelty may be questioned. However, in view of the striking experimental demonstrations which may be carried out on critical angles, total internal reflection, etc. and in view of the fact that the instrument appears to be unknown, a brief description will be justified.

Essentially, the refractometer consists of a plane-parallel glass plate having the approximate dimensions 10x10x0.5 cms. The lower surface of this plate is coated with white paint which is allowed to dry. From above (as shown in Fig. 1) a brilliant "point-image" of an auto head-

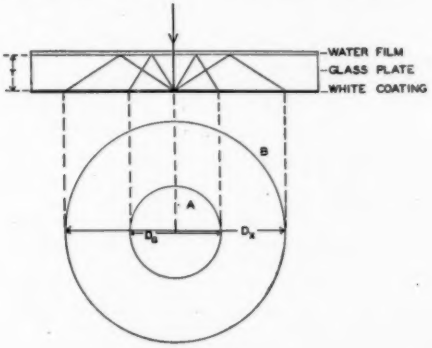

Fig. 1.

light lamp is projected on the glass-paint interface. This image acts as a new source of light which sends out rays in all directions. At the angles of emergence equal to and greater than the critical angle all rays are returned to the lower white surface, thus producing an illuminated area which has a black circular disc A at its center. If a film of water be spread over the upper surface, a second and larger circular ring B makes its appearance. As is evident this ring is due to rays which are totally reflected at the glass-water interface. From a knowledge of the plate thickness and ring-diameters, refractive indices may be calculated.

Let t = plate thickness in cm.

n_g = refractive index of glass plate

n_x = refractive index of liquid covering glass plate
D_0 = diameter of central disc (no liquid on glass plate)
D_x = diameter of outer ring (liquid *on* glass plate)

then it follows, simply, that:

$$n_0 = \frac{\sqrt{D_0^2 + 16t^2}}{D_0}$$

$$n_x = n_0 \cdot \frac{D_x}{\sqrt{D_x^2 + 16t^2}}.$$

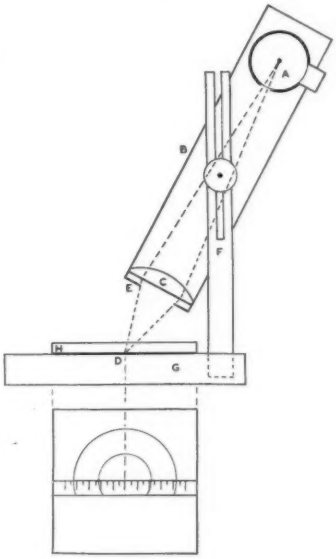

FIG. 2.

For exercises to be carried out by students, a good grade of plate glass of about 7mm thickness will do. For such purposes it is advantageous to remove the white paint over half the area of the plate and to attach a millimeter scale of white celluloid with Canada balsam (see lower part of Fig. 2). Since ring-diameters may be read off the scale with a reading glass to 0.1 mm, the refractive index n_x is determined to the third decimal place. In view of the relatively low refractive index of plate glass, the liquids studied had best not exceed 1.48 in refractive index. Water and solutions of glycerine in water are very satisfactory

materials. To increase the range of usefulness, the use of a plate of heavy flint glass ($n \geqq 1.7$) will be found necessary.

The simple instrument shown in Fig. 2 has been developed. Here A is an auto head-light bulb well blackened, but for a small window, with lamp-black, water glass and a little glycerine. The containing tube B is lined with black velvet. The "point image" D of the lamp filament is formed by means of the lens C which effects a reduction in the ratio of about 1:10. So as to reduce spherical aberration a diaphragm is intro-

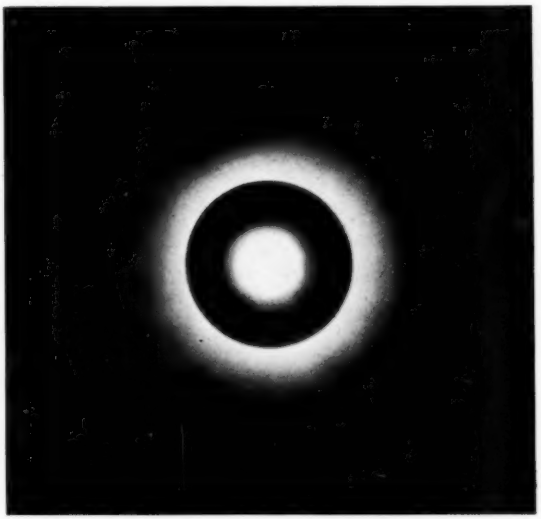

FIG. 3A—*Wa'er* ($n=1.333$) *film on upper surface of glass plate.*

duced at E. The tube is held in a slotted vertical bar F which, in turn is attached to the base-plate G. Sharp focusing of the filament image on the lower, white surface of the refractometer plate H is brought about by changing tilt of the tube B.

The appearance of the rings is shown in Fig. 3 where the outer ring in $3A$ is due to a film of water ($n=1.333$) while the outer ring in $3B$ is due to a glycerine-water solution ($n=1.392$). These photographs were obtained without the use of a camera. It was merely necessary to use a clear plate H whose lower surface rested on a sensitive photographic plate whose upper surface had previously been coated with glycerine.

After an exposure of a few seconds, the glycerine was washed off the plate which was then developed in the usual manner.

In spite of the fact that the filament-image D (Fig. 2) is far from being a point image, the sharpness of the rings is remarkable. The absence of chromatic effects at the ring is due to a process of achromatization brought about by a relatively constant ratio of the refractive index of glass to that of water throughout the spectrum. Repeated trials have shown that ring-diameters may be measured to an accuracy

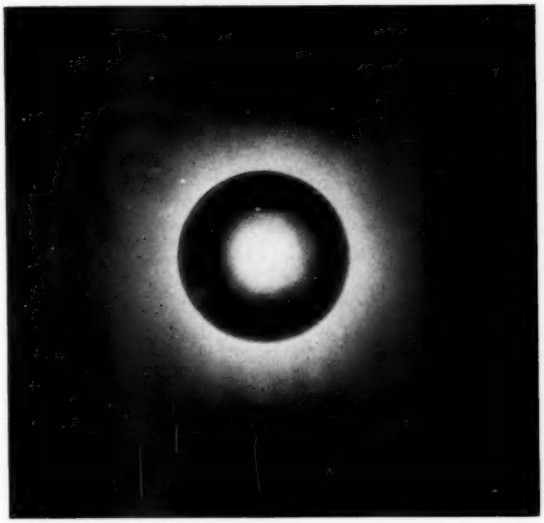

FIG. *3B—Glycerine-water* ($n=1.392$) *film on upper surface of glass plate.*

of ± 0.03 mm on a dividing engine supplied with long-focus microscope of unit magnification. Under these conditions refractive indices may be carried into the fourth decimal place.

Without going into details it may be stated that by making use of multiple reflections (of which as many as seven have been observed) the accuracy of measurement may be greatly increased. At some future time it is intended to develop a precision instrument of great sensitivity along these lines. While a number of very excellent refractometers are already in existence, the plate-refractometer is especially useful in the study of such problems as the changes in refractive index

upon the "drying" of oils. A dozen samples may be studied at the same time (on the same refractometer plate) and no immersion fluid is necessary.

Finally, another manifestation of critical angle may be illustrated by means of this refractometer. If the paint on the lower surface of the refractometer plate be removed over a small central area and if a flake of paint-film, moistened with water be pressed against this area a very thin layer of water will lie between paint and glass. If now the point image

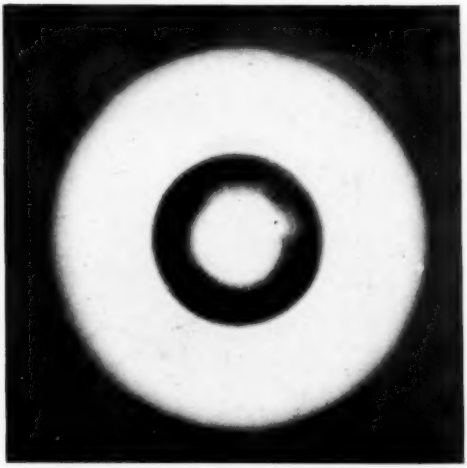

FIG. *3C—Water film on lower side of glass plate.*

be projected on this water-film, a phenomenon such as is shown in Fig. 3C will be observed. (The plate used was not the same as that employed to obtain Figs. 3A and 3B.) The outer edge of the white annular ring is obviously due to those rays within the water film which are essentially parallel to the lower surface of the glass plate and which enter at the critical angle. As before, these rays are totally reflected at the upper glass-air surface and are returned to the white coating. In the preparation of Fig. 3C it was again unnecessary to employ a camera. An ordinary photographic plate was soaked in water for a few minutes whereupon the clear refractometer plate was laid on the wet emulsion. By applying slight pressure, the imprisoned water film was rendered very thin. After exposing the plate in the apparatus (Fig. 2) development followed in the usual manner.

* Presented Charlottsville Meeting of the Optical Society of America, Nov. 1, 1930.

THE PROPAGATION OF ENERGY BY WAVES AND THE AMPLITUDE OF A LIGHT WAVE

By W. W. Sleator

[University of Michigan, Ann Arbor, Michigan.
Received Nov. 4, 1930]

The ideas presented in this paper were collected and arranged in preparation for courses in sound and light, and perhaps their systematic presentation will be interesting to other teachers. While entirely elementary these ideas are not as familiar as they very well might be.

Suppose a body of mass M to move horizontally without friction under the influence of a spring which follows Hooke's Law, so as to have simple harmonic motion. K is the spring factor, dF/dl, the restoring force per unit of extension. There are two ways of deriving the formula $T=2\pi\sqrt{M/K}$ for the period of the motion. One is to use the relation $F=Ma$. The other is to equate the maximum kinetic energy resident in the mass to the maximum potential energy resident one quarter period later in the spring. One may proceed by either of two methods strictly analogous to these to find the expression for the velocity of plane waves. This is my thesis, and I proceed to the discussion of waves in a rope, sound waves, and light or electromagnetic waves. By making use of an advantageous energy relation it will be possible to handle the three types of waves in precisely similar fashions.

I. a. Let progressive waves of small amplitude be maintained in a flexible string whose mass per unit length is m. The tension or stretching force in the cord is F. Unit length of the cord has energy in the kinetic form when it is in motion. If u represents the displacement of a bit of cord from its equilibrium position, that position being the X axis, and u being measured along Y, and if s is $\partial u/\partial t$, or the speed, then T is the kinetic energy per unit length, and

$$T=\frac{1}{2}m\left(\frac{\partial u}{\partial t}\right)^2=\frac{1}{2}ms^2.$$

In harmonic waves T has its maximum value when (or where) $u=0$.

We will call the potential energy per unit length V. It is the work necessary to produce any displacement or configuration of the unit length without the corresponding motion. If the amplitude is small the slope of the string $\partial u/\partial x$ may be represented by the angle θ, the inclination of the cord to the X axis, and $V=\frac{1}{2}F\theta^2$.

This is not the conventional expression for potential energy per unit

length. In fact it is common to say that potential energy is a maximum where u, not θ, is greatest, while the expression gives potential energy greatest where kinetic energy is also a maximum. However, authority for the statement is not lacking.[1] I give a simple proof only because the proof given by Lamb requires an extension or stretched portion of the string to travel along with the transverse wave, and in general longitudinal and transverse waves in a rope will not travel together.

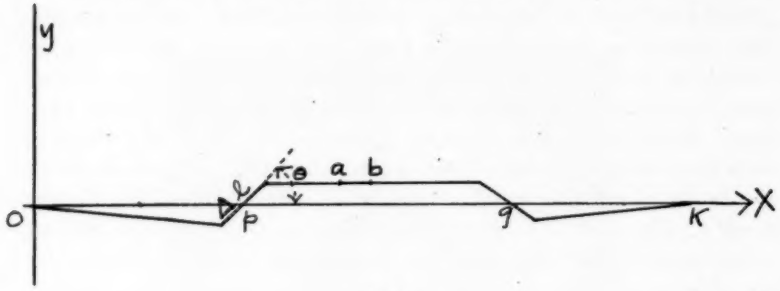

FIG. 1.

In Fig. 1 Δl represents any bit of the cord inclined by θ to the X axis. If the string does not stretch one end must have been pulled along by an amount $\Delta l - \Delta l \cos\theta$ when Δl was tipped, and the work necessary is given by

$$W = F\Delta l(1 - \cos\theta)$$
$$= F\Delta l\theta^2/2$$

if θ is small, so that, since

$$V = W/\Delta l,$$
$$V = \tfrac{1}{2}F\theta^2.$$

Whether the string may stretch or not the two forms of energy must have maximum values where u is zero. For suppose a massive vibrator, as one arm of a tuning fork, to maintain continuously the progressive transverse wave train. It can do work on the string only while it is in motion, and consequently the energy communicated per unit length will be a maximum where s and θ are greatest and zero at the turning point, where θ is zero. A formal proof may be readily set down for the case where the rope is capable of stretching.

[1] H. Lamb—Article Waves, Encyc. Britannica, 11th Edition. Also "Dynamical Theory of Sound," Section 22, where a proof is given.

It is conventional to apply the principle of conservation of energy to a particle of a cord, and to say that the kinetic energy, maximum when u is 0, becomes an equal amount of potential energy one quarter period later when the displacement is maximum. But the energy does not go back and forth across the X axis—it travels with uniform speed parallel to that axis. Also the two forms are together in phase and continually equal.

This equality gives directly the expression for the speed of the disturbance. In Fig. 2 the advance of the waves would be represented if the curve could move forward without change of shape and with uni-

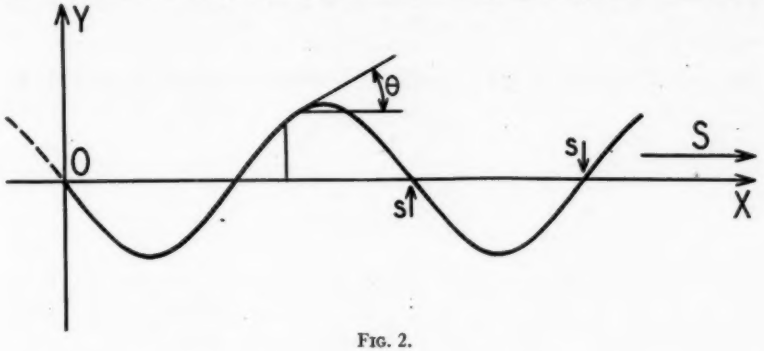

FIG. 2.

form speed S. In Fig. 3 (which is given in the "Dynamical Theory of Sound") AB is a piece of rope, and $A'B'$ another piece which a little later has taken exactly the same phase and shape. In the interval B has gone to C' but the wave has traveled a distance CC'. Accordingly, s being the velocity of the particle and S that of the waves,

$$s/S = -\theta, \text{ or } s = -S\theta.$$

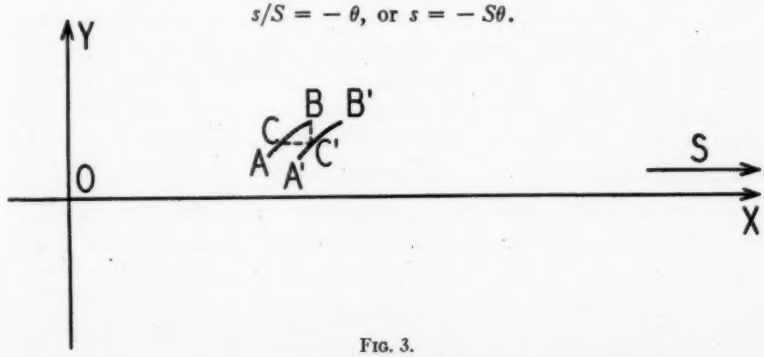

FIG. 3.

This is an important and quite general relation, which may be shown more rigorously in another way.

The displacement u is always some function of x and t, that is, $u=f(x, t)$ and

$$du = \frac{\partial u}{\partial x}dx + \frac{\partial u}{\partial t}dt. \tag{1}$$

If both x and t so change that $du=0$ then $dx/dt=S$. For to remain at a place in the medium where u does not change is to travel with the speed of the waves. Therefore

$$S = -\frac{\partial u/\partial t}{\partial u/\partial x}, \text{ or } S = -\frac{s}{\theta}, \tag{2}$$

as before.

But now, if for any segment of the cord potential energy equals kinetic,

$$\tfrac{1}{2}F\theta^2 = \tfrac{1}{2}ms^2,$$

so that

$$\frac{s}{\theta} = \sqrt{\frac{F}{m}}.$$

Therefore

$$S = \sqrt{\frac{F}{m}}. \tag{3}$$

This is the ordinary expression for the speed of the waves. That the two forms of energy in the same bit of rope are always equal may be called our hypothesis, though one might go back to it as a conclusion if he accepted or otherwise proved the expressions for S and V. The same equality of course holds in sound,[2] and in light, where the electric and magnetic fields are together in phase.

I. b. The displacement of a particle from the neutral line, which is called u, is a vector quantity. Equation 1 refers to its magnitude only. It is possible now to give a picturesque account of these waves by recognizing u as a vector. For the vectors u and x the partial derivative $\partial u/\partial x$ is not defined. But by the ordinary expansion, i, j, and k being unit vectors along x, y, and z respectively,

$$\text{curl } u = \begin{vmatrix} i & j & k \\ \dfrac{\partial}{\partial x} & \dfrac{\partial}{\partial y} & \dfrac{\partial}{\partial z} \\ u_x & u_y & u_z \end{vmatrix}.$$

[2] I. B. Crandall—Theory of Vibrating Systems and Sound. P 90.

In our case
curl $\boldsymbol{u} = k\partial u_y/\partial x$, a vector along the z axis. We have used $\partial \boldsymbol{u}/\partial x$ as θ, and we now have a vector $\boldsymbol{\theta}$, so that curl $\boldsymbol{u} = \boldsymbol{\theta}$ and our equation 1 becomes

$$d\boldsymbol{u} = \boldsymbol{\theta} \times d\boldsymbol{x} + \boldsymbol{s}dt \tag{4}$$

where $\times$ indicates a vector product, and if

$$d\boldsymbol{u} = 0, \frac{d\boldsymbol{x}}{dt} = \boldsymbol{S},$$

so that

$$\boldsymbol{S} \times \boldsymbol{\theta} = \boldsymbol{s}. \tag{5}$$

This is the vector form of the equation $S\theta = -s$. This important relationship holds for any transverse vector whose value characterizes the waves, for example

$$\boldsymbol{S} \times \text{curl } \boldsymbol{s} = \frac{\partial \boldsymbol{s}}{\partial t},$$

$$\boldsymbol{S} \times \text{curl } \boldsymbol{\theta} = \frac{\partial \boldsymbol{\theta}}{\partial t}.$$

By using Newton's Second Law for the transverse motion of a particle we have, as usual,

$$F\frac{\partial^2 u_y}{\partial x^2} = m\frac{\partial^2 u_y}{\partial t^2}. \tag{6}$$

But since

$$\text{curl } \boldsymbol{u} = k\frac{\partial u_y}{\partial x} = \boldsymbol{\theta}, \text{ and } \frac{\partial \boldsymbol{u}}{\partial t} = \boldsymbol{s},$$

equation 6 becomes

$$\text{curl } \boldsymbol{\theta} = -\frac{1}{F/m}\frac{\partial \boldsymbol{s}}{\partial t}. \tag{7}$$

Also, since the order of differentiation is immaterial, curl $\partial \boldsymbol{u}/\partial t \equiv \partial/\partial t$ curl $\boldsymbol{u}$, and

$$\text{curl } \boldsymbol{s} \equiv \frac{\partial \boldsymbol{\theta}}{\partial t}, \tag{8}$$

an identity.

Equations 7 and 8 are analogous to two of the Maxwell equations if one uses in them a single system of units. We may eliminate either $\boldsymbol{s}$ or $\boldsymbol{\theta}$, and obtain, for example,

$$\frac{\partial^2 s}{\partial x^2} = \frac{1}{F/m}\frac{\partial^2 s}{\partial t^2} \tag{9}$$

which tells the same thing about s that equation 6 has given already about u. In either case the solution

$$u(\text{or } s) = f\left(t - \frac{x}{\sqrt{F/m}}\right) \tag{10}$$

shows that $\sqrt{F/m}$ is the velocity of the waves.

A word may be added about stationary waves in a cord, which are a combination of two equal and oppositely traveling trains of progressive waves. At any two points in the medium where the two particle speeds, —say $\mathbf{s}$ and $\mathbf{s}'$, are equal (in magnitude and direction) the two vectors $\boldsymbol{\theta}$ and $\boldsymbol{\theta}'$ are equal and opposite, and vice versa. In fact in either train the cross product $\boldsymbol{\theta}\times\mathbf{s}$ is a vector in the direction of propagation and $F(\boldsymbol{\theta}\times\mathbf{s})$ is the Poynting vector for such a train. Therefore where the waves so meet that maximum velocities numerically add the inclination is always zero and these places are antinodes. Here the energy is all kinetic. At the nodes on the other hand the two inclinations reinforce one another and the speeds are equal and opposite. No energy flows past a node, or past an antinode, but there is a backward and forward flow with change of type in between.

II. a. Very little need be said in order to present a complete analogy to the foregoing sections for the case of sound, and I may set down the appropriate equations, of which no. 11 corresponds with 1, 12 with 2, etc., without much explanation. Just as before the displacement u, in this case longitudinal, is a function of x and t so that

$$du = \frac{\partial u}{\partial x}dx + \frac{\partial u}{\partial t}dt. \tag{11}$$

Accordingly the velocity is given by

$$S = -\frac{\partial u/\partial t}{\partial u/\partial x} = \frac{-s}{\Delta V/V},$$

since $\partial u/dx$ is the change in volume per unit volume, properly the strain. If C is the condensation or $-\Delta V/V$,

$$S = \frac{s}{C}. \tag{12}$$

The kinetic energy per unit volume in the medium of density ρ is $\frac{1}{2}\rho s^2$. The potential energy per unit volume in an elastic medium under distortion is in general $\frac{1}{2}$ stress times strain, or $\frac{1}{2}$ n strain^2,

n being the appropriate coefficient of elasticity. In a small volume of the medium having maximum velocity the strain is maximum also, as equation 12 shows, since S is constant.[3] The two forms of energy are again together in phase and everywhere equal. Accordingly $\frac{1}{2}\, nC^2 = \frac{1}{2}\rho s^2$ and $s/C = \sqrt{n/\rho}$, so that

$$S = \sqrt{\frac{n}{\rho}}. \tag{13}$$

This, with appropriate values for n, gives the speed of plane compressional waves in any medium. For air of course $n = \gamma P$. It is not difficult to find descriptions of sound waves in which the energy of a small volume is said to be alternately all kinetic and all potential—or that "when one form of energy is a maximum the other is zero."[4] This is evidently not the case.

$S = s/C$ is one form of the "equation of continuity." If similar washers are spread evenly along a horizontal rod, with the spaces between say twice as thick as one washer, and then the end washer is pushed along the rod so as to gather up the others into a solid moving column, one may see at once that the two speeds involved have the relation given by Eq. 12.

II. b. In Equation 11 u is treated as a scalar, but really $\boldsymbol{u}$ is a vector quantity just as before. For sound waves in general

$$\frac{\Delta V}{V} = -C = \operatorname{div} \boldsymbol{u}.$$

If the waves are plane, $-C = \partial u_x/\partial x$. Then equation 11 becomes

$$d\boldsymbol{u} = \operatorname{div} \boldsymbol{u} d\boldsymbol{x} + \frac{\partial \boldsymbol{u}}{\partial t} dt, \text{ or}$$

$$d\boldsymbol{u} = -C d\boldsymbol{x} + \frac{\partial \boldsymbol{u}}{\partial t} dt. \tag{14}$$

If $d\boldsymbol{u} = 0$, $S = d\boldsymbol{x}/dt$, so that

$$\boldsymbol{SC} = \boldsymbol{s}, \tag{15}$$

[3] I have noticed in a recent text book the statement that "there is no relation between the velocity of the wave and the velocity of the medium" True, as I suppose the author meant, one cannot compute s from S alone. But equation 12 is such a relation and an important one.

[4] E. H. Barton—A Textbook on Sound, article 145, p. 211. He says, in the next article, that E and C, energy and energy current, "are each independent of x and t." This is also a mistake.

which represents not only the magnitudes of equation 12, but their directions also. Similarly

$$\boldsymbol{S}\,\mathrm{div}\,\mathbf{s} = -\frac{\partial \mathbf{s}}{\partial t}$$

and

$$\boldsymbol{S}\cdot\mathrm{grad}\,C = -\frac{\partial C}{\partial t},$$

(scalar product).

If we again make use of the second law we have directly what might be called the sound analogues of Maxwell's equations,

$$\mathrm{grad}\,C = -\frac{1}{n/\rho}\frac{\partial \mathbf{s}}{\partial t} \tag{17}$$

$$\text{and} \quad \mathrm{div}\,\mathbf{s} \equiv -\frac{\partial C}{\partial t}, \tag{18}$$

an identity. Then elimination gives

$$\frac{\partial^2 C}{\partial x^2} = \frac{1}{n/\rho}\frac{\partial^2 C}{\partial t^2}, \tag{19}$$

and shows that

$$C(\text{or } u) = f\left(t - \frac{x}{\sqrt{n/\rho}}\right), \tag{20}$$

as before.

The total energy per unit volume of the medium is nC^2. Therefore unit area of a stationary absorbing surface, at which the condensation happens to have the value C, is receiving energy at the rate nC^2S per square cm per sec. Since $\boldsymbol{S}C = \mathbf{s}$, $nC\mathbf{s}$ may properly be called the Poynting vector for sound. It is this product, not the energy resident in the medium, which determines the intensity of a sound, and although in plane waves these two quantities are proportional, with spreading or divergent waves it is not so. The flow of energy in plane progressive waves is periodic and harmonic, but not alternating, having a frequency twice that of the displacement. In precise correspondence the power curve for an alternating current has double the frequency of the current itself.

III. It ought to be easy to obtain now the standard expression $c/\sqrt{\epsilon}$ for the velocity of light, and this in fact is the purpose of the present section. To follow the same process however requires first that two

quantities whose squares give values for energy, and which are the analogues of θ and s in the rope case, should be given as partial derivatives of a single quantity u. Magnetic field H and electric field E, or magnetic field and electric induction D, are such quantities, and the question arises—"May there be a quantity u associated with an electromagnetic wave just as transverse displacement is related to waves in a rope?" The answer to this question is that the equations

$$\left.\begin{aligned} &\text{curl } \boldsymbol{u} = \boldsymbol{D} = \epsilon \boldsymbol{E} \text{ and} \\ &\frac{\partial \boldsymbol{u}}{\partial t} = \boldsymbol{H} \end{aligned}\right\} \qquad (A)$$

give the quantity $\boldsymbol{u}$ which is required. With $\boldsymbol{D}$ and $\boldsymbol{H}$ distributed as they are in a plane light wave this quantity $\boldsymbol{u}$ may certainly exist. The proof of its reality lies in considerations of the dimensions, directions and magnitudes of the three quantities involved.

In the first place—keeping to the electrostatic system of units, $[DL] = [HT] = [u] = [M^{\frac{1}{2}}L^{\frac{1}{2}}L^{-1}\epsilon^{\frac{1}{2}}]$, so that at any rate dimensions do not forbid the existence of u. Also, if

$$u = ju_y, \quad u_x = u_z = 0,$$

curl $\boldsymbol{u} = k\ \partial u_y/\partial x$, which is a vector along Z, and $\partial u/\partial t$ is a vector along Y, as $\boldsymbol{u}$ is also. If u is any function of $(t - x/S)$, $\partial u_y/\partial x$ is of opposite sign to $\partial u_y/\partial t$. Therefore whenever curl $\boldsymbol{u}$ is positive along Z in a right hand set $\partial u/\partial t$ is negative along Y. Therefore equations A give

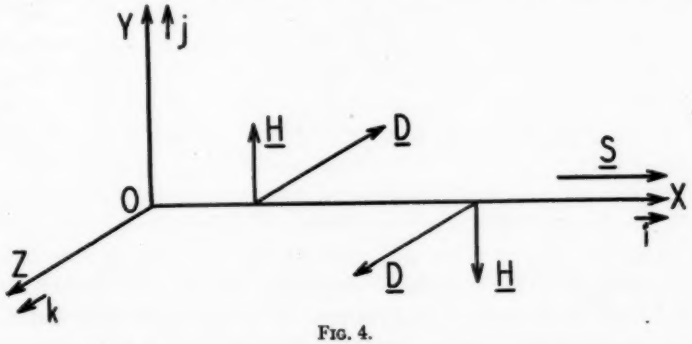

FIG. 4.

$E \times H$ or $D \times H$ in the direction of propagation. Fig. 4 shows $\boldsymbol{S}$ in the direction of $+X$, and $\boldsymbol{H}$ positive along Y when $\boldsymbol{D}$ is negative on Z.

There remains the question of magnitude, for equations A might

demand at the same time two different sizes for u. In precise correspondence with equations 1 and 11, u being used as a scalar,

$$du = \frac{\partial u}{\partial x}dx + \frac{\partial u}{\partial t}dt, \tag{21}$$

and if $du = 0$,

$$S = \frac{dx}{dt} = -\frac{\partial u/\partial t}{\partial u/\partial x},$$

so that

$$S = -\frac{H}{D}. \tag{22}$$

To find the value of S we assume the same equality of energies as before. The energy per unit volume in the electric field is w_1 and $w_1 = D^2/2\epsilon$. Also the energy per unit volume of the magnetic field is W_2 and $w_2 = H^2/2$ if H is in rational magnetic units. But equations A are to be kept in the static system. In a given field the ratio

$$\frac{\text{Number of esu of } H}{\text{Number of emu of } H} \text{ equals the ratio}$$

$$\frac{\text{Number of esu of current}}{\text{Number of emu of current}} \text{ in a given current. This ratio is } 3 \cdot 10^{10},$$

which we call c. Therefore

$$W_2 = \frac{H^2}{2c^2}.$$

$$\text{Then if} \quad W_1 = W_2, \quad \frac{D^2}{2\epsilon} = \frac{H^2}{2c^2},$$

$$\text{so that} \quad \frac{H}{D} = \frac{c}{\sqrt{\epsilon}} = S. \tag{33}$$

The comparison of dimensions, directions and magnitudes seems to justify the invention of u. It is of course a vector potential, but it is not the one commonly used, which is given by curl $A = H$. It is not a degenerate Hertzian vector P for in spherical waves H is given by $1/c$ curl $\partial P/\partial t$, which shows that when the spreading waves become nearly plane H and P become perpendicular.

A fair case may be made for calling u the light vector and its maximum value U the amplitude of the wave. In the first place according to equations A the expression

$$u = ju_y = U \sin \frac{2\pi}{T}\left(t - \frac{x}{S}\right)$$

completely describes a plane, plane polarized, and harmonic light wave, for H and D are included in the description, just as velocity and condensation are included in the usual expression, in terms of linear displacement, for a sound wave. A single differentiation of u gives either field. Also if maximum electric field is taken as amplitude we say that the energy conveyed is proportional to the square of the amplitude and independent of the frequency, while in mechanical waves it is common to give the power as proportional to the product of frequency squared and amplitude squared. Also it is convenient that u lies in the plane of polarization of plane polarized waves. It is of course a matter of choice, determined by one's purpose, what he will call the amplitude of a wave train.

One more word about the vector u. It will be remembered that Lord Kelvin's objection to Maxwell's theory, (which is echoed by Schuster in the preface to his optics) arose from his perplexity about the nature of the "displacements" whose variation constituted the propagation of light. The linear displacement of a medium from its position of equilibrium is not to be looked for in a vacuum, and if there were any such displacement our u ought to come out a length. But u is not measured in centimeters, although it occupies in light waves the position taken in mechanical waves by a linear displacement. To talk of an ether is to suggest a "subject for the verb undulate," a something moving. One may of course speak of the ether as a medium for the propogation of electromagnetic waves. But to do so is to convey to students the idea of a thin quivering jelly whose "undulations" are changes in position. Not only is the ether not a jelly, but also its "displacement" is not measured in centimeters—nor its velocity in centimeters per second. For the electromagnetic theory the ether has never meant anything more than space.

The vector u was suggested in order that we might write equation 21, and by taking account of the directions also we should have, just as in the foregoing sections,

$$du = D \times dx + \frac{\partial u}{\partial t} dt \qquad (24)$$

and therefore

$$\boldsymbol{S} \times \boldsymbol{D} = \boldsymbol{H}. \tag{25}$$

Similarly $\boldsymbol{S} \times \text{curl } \boldsymbol{H} = \partial \boldsymbol{H}/\partial t$ and $\boldsymbol{S} \times \text{curl } \boldsymbol{D} = \partial \boldsymbol{D}/\partial t$.

If one writes the Maxwell equations as

$$\frac{1}{c}\frac{\partial \boldsymbol{H}}{\partial t} = -\text{ curl } \boldsymbol{E}$$

$$\frac{1}{c}\frac{\partial \boldsymbol{D}}{\partial t} = \text{curl } \boldsymbol{H},$$

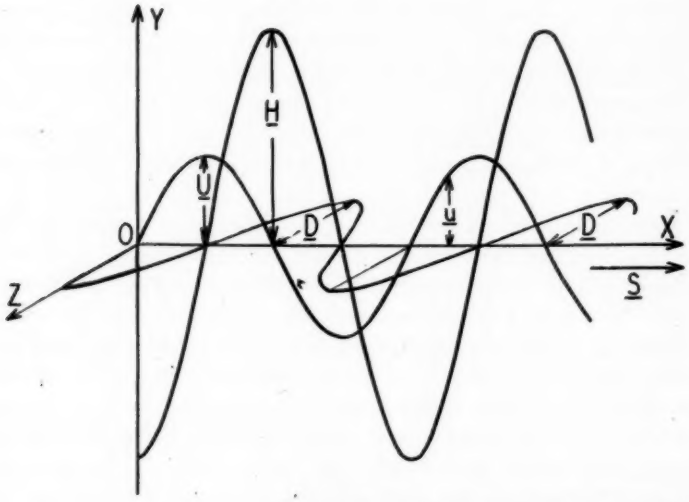

FIG. 5.

holding where the permeability of the medium is unity, then $\boldsymbol{H}$ is in magnetic and $\boldsymbol{E}$ and $\boldsymbol{D}$ in electric units. If we use the latter system only, and introduce our u, they become

$$\frac{1}{c^2}\frac{\partial \boldsymbol{H}}{\partial t} = -\frac{1}{\epsilon}\text{curl } \boldsymbol{D} \tag{27}$$

$$\frac{\partial \boldsymbol{D}}{\partial t} \equiv \text{curl } \boldsymbol{H}, \tag{28}$$

where 28 is an identity, since $\partial/\partial t$ curl $u \equiv$ curl $\partial u/\partial t$. Elimination gives as before

$$H = f\left(t - \frac{x}{c/\sqrt{\epsilon}}\right). \tag{30}$$

It has not been necessary to include all the equations anolagous to those in the other sections. In Fig. 5, where u is in the XY plane, H and D should show a ratio equal to S.

IV. In terms of u it is easy to describe the passage of light from one transparent medium to another. The vector u is quite continuous at the surface of separation; neither in its parallel nor its normal component is there any discontinuity. Then since the frequency does not change in the passage, H or $\partial u/\partial t$ is also continuous. But if the wave

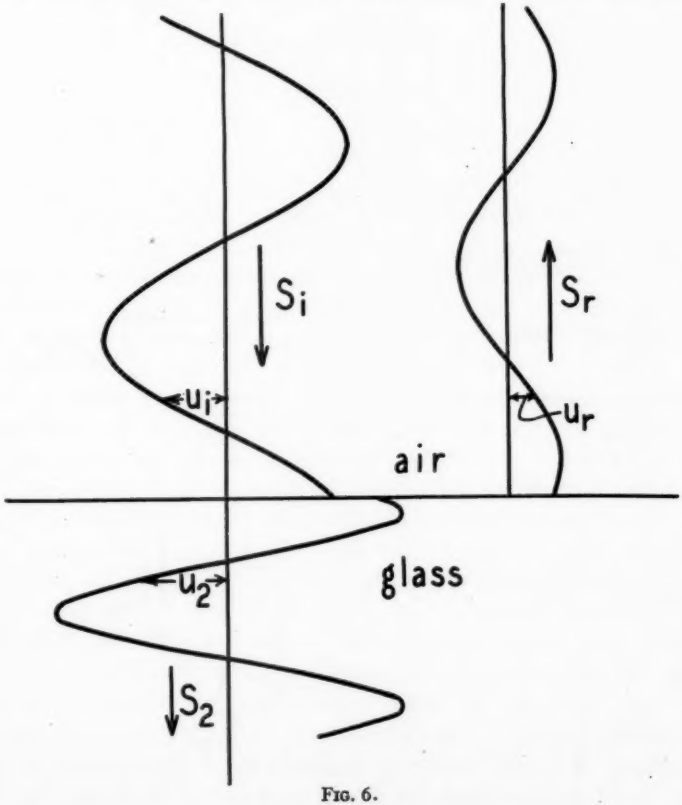

FIG. 6.

length is different there will be a break in D which is a space rate of change. The energy per square cm per second conveyed by the wave, being proportional to $E \times H$, is proportional to $u^2/\sqrt{\epsilon}$. Accordingly, for the case of normal incidence, if i, r, and 2 represent incident, reflected and refracted rays respectively,

$$u_i^2 - u_r^2 = \frac{u_2^2}{\sqrt{\epsilon}}$$

and since u is continuous,

$$u_i + u_r = u_2$$

Therefore

$$u_i - u_r = \frac{u_2}{\sqrt{\epsilon}}$$

and

$$u_i + u_r = \sqrt{\epsilon}(u_i - u_r)$$

so that

$$\frac{u_r}{u_i} = \frac{\sqrt{\epsilon} - 1}{\sqrt{\epsilon} + 1} = \frac{\mu - 1}{\mu + 1} = \frac{E_r}{E_i}.$$

Figs. 6 and 7 explain themselves.

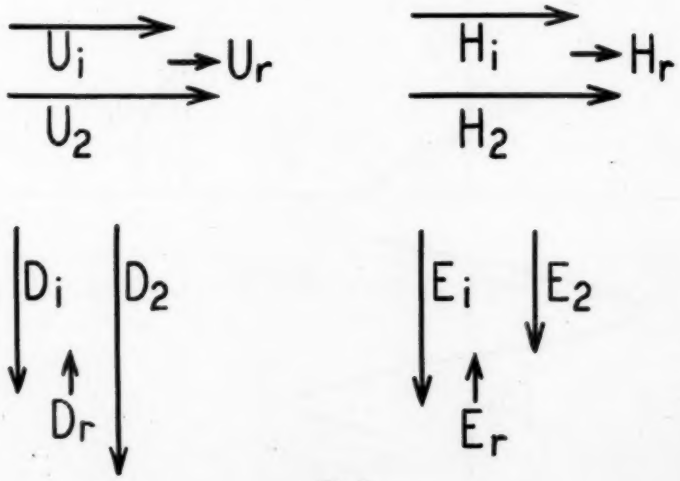

FIG. 7.

For oblique incidence, Fresnel's equations follow at once. If u lies in the plane of incidence the situation is shown in Fig. 8.

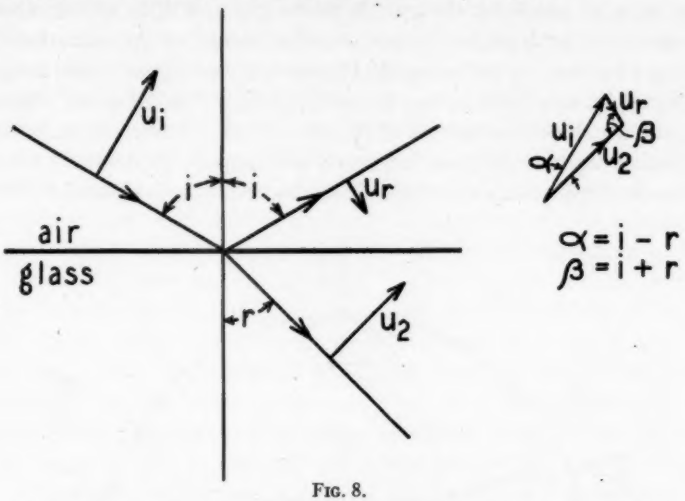

FIG. 8.

The equality of u_i+u_r and u_2 is a vector relation. If the lines in the figure represent u at the boundary they must form a triangle, where $\alpha=(i-r)$ and $\beta=(i+r)$. Therefore $u_r/u_i=\sin(i-r)/\sin(i+r)$ which is the first of the usual relationships. The triangle of values of u brings out most clearly the intimate relation between the amount of bending suffered by a ray on entering a new medium and the amount of light reflected from its surface.

V. A displacement of the material from its equilibrium position is characteristic not only of mechanical waves but exists in any medium under strain. One might ask then, may we expect to find a u accompanying every D? It is possible of course to find for certain distributions of D the corresponding u, such that curl $u=D$. For example if E_1 is the uniform field between the extended parallel plates of a charged condenser, then if E_1 lies along X in the right hand set, u may lie along Y, and may change only as one moves in the direction of Z. Again let the field be that about an isolated point charge q so that $D=\epsilon E=qr_1/r^2$ where r_1 is the unit vector away from q. This D is to be given by curl u. Then $u=q(\cot\theta/r)\ t_1+\text{grad}\ M$ where M is any scalar. The unit vector t_1 and therefore $q(\cot\theta/r)t_1$, lies along parallels of latitude, as shown in Fig. 9. The value of u may be checked by Stokes' Theorem. Accordingly u manifests an axial symmetry, though no choice of axes.

VI. A numerical value may be found for the light vector u in some particular light beam, but there is no obvious name for its unit because we have no name for the unit D, or for the unit H in the electrostatic system. If an harmonic beam conveys energy at the same rate as it is sent by the sun to the earth, the maximum magnetic field involved, which is independent of the frequency, is about 0.04 Gauss. Therefore in the usual electric units H is $12 \cdot 10^8$. U will be different according as different wave lengths are assumed, but suppose $\lambda = 0.000055$ cms and that the medium is a vacuum. Then the frequency is about $5.5 \cdot 10^{14}$ and

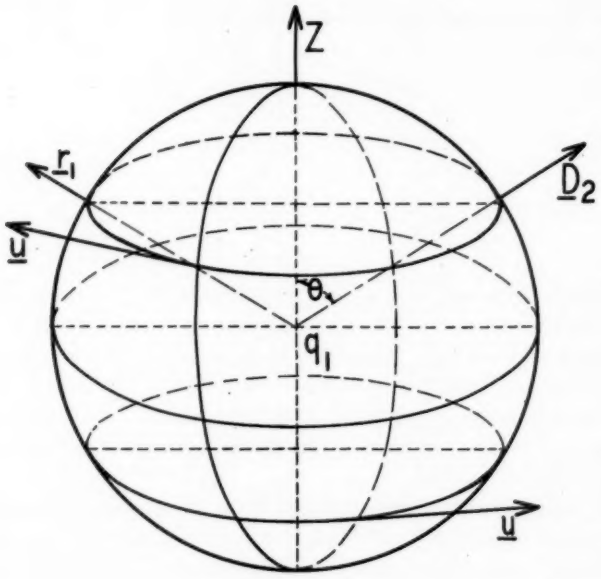

FIG. 9.

maximum $u = U =$ maximum $H \div 2\pi\nu = 3.5 \cdot 10^{-7}$. This is the value of U in ordinary electrostatic units—in rational units it is about 10^{-7}. This may be checked by computing from the value of D.

Like any vector, u may, for want of a better unit, if it is parallel to Y, be expressed as a number of lines per square cm in the XZ plane, and the change per cm in this number (the cm being measured along X, the line of propagation) gives the number of lines per cm² of the vector D (this sq cm being in the XY plane). The number of lines per cm² by which u decreases in one cm along X gives the actual number of lines of

$\boldsymbol{D}$ per cm², so that it is as if the decrease were not a loss but a timeless rotation through 90° (about X) of the lines of $\boldsymbol{u}$. The integrated $\boldsymbol{D}$ over the proper quarter wave length gives maximum $\boldsymbol{u}$. This picture of the relation curl $\boldsymbol{u} = \boldsymbol{D}$ shows the significance of the term rotation as used instead of curl. In the same way, if we consider a sq cm of the XZ plane while the wave progresses along X, the time rate of change in the number of lines of $\boldsymbol{u}$ in this square cm gives the number of lines of $\boldsymbol{H}$ in the same square cm, so that we need not think of the lines of $\boldsymbol{u}$ as being annihilated, but as, immediately upon their disappearance, reappearing as lines of $\boldsymbol{H}$. Hence the value of $\boldsymbol{H}$ integrated over a quarter period, (if that interval begins when $\boldsymbol{H}=O$) gives maximum $\boldsymbol{u}$ or $\boldsymbol{U}$. These lines of $\boldsymbol{H}$ exist at a certain place, but the number of them in any square cm is the number of $\boldsymbol{u}$ lines which disappear per second $(\partial \boldsymbol{u}/\partial t)$, not the total number which has disappeared. Hence we ought to have a fourth dimension, (perpendicular to X and Y and Z), along which the accumulated $\boldsymbol{H}$ lines could move out of our three dimensional picture (at 1 cm per sec) leaving in one square cm only as many as the change in one second in the number (in one square cm) of the $\boldsymbol{u}$ lines. With such a dimension available (from which also on demand the lines of $\boldsymbol{H}$ return) one could ascribe a sort of indestructibility or immortality to the lines of $\boldsymbol{u}$.

One more useful property of the light vector $\boldsymbol{u}$. Since the defining equations

$$\text{curl } \boldsymbol{u} = \boldsymbol{D}, \quad \frac{\partial \boldsymbol{u}}{\partial t} = \boldsymbol{H}$$

are to hold in all cases (where the permeability is one) they should represent the propagation of a plane wave as well in any crystalline as in an isotropic medium. And although $\boldsymbol{E}$ and $\boldsymbol{H}$ are not in general normal in crystalline media, $\boldsymbol{D}$ and $\boldsymbol{H}$ always are, as indeed their derivation from $\boldsymbol{u}$ shows them to be. The line of propagation of energy, given by $\boldsymbol{E} \times \boldsymbol{H}$, is always perpendicular to $\boldsymbol{u}$.

It should be interesting to describe the behavior of $\boldsymbol{u}$ in spherical radiation and to study the connection of spherical radiation with Huygens' Principle. One might also develop further in these terms the propagation of light in crystals.

It seems to me that in beginning the study of light students get the idea that electromagnetic waves are more complicated than mechanical waves. Since the former involve two vector quantities of equal importance, the electric and magnetic fields, which lie in different planes,

it seems to be necessary for the student to keep in mind two simultaneous vibrations and two equally real amplitudes. In mechanical waves only one at a time seemed to be required. I have tried to show how this difficulty may be avoided. It seems to make the situation simpler also if one can obtain the expression for either field by a single differentiation instead of having to go from one to the other by two processes as the Maxwell equations suggest. They seem to leave out something in between $\boldsymbol{E}$ and $\boldsymbol{H}$ which ought to be just as fundamental as these fields are.

Artificial Sunlight.—By M. Luckiesh, D.Sc., Director Lighting Research Laboratory, Edison Lamp Works, General Electric Company. Published by D. Van Nostrand Co. Inc., 1930; 254 pages. Price $3.75.

This is an account of a recent development in illuminating engineering which has provided a light source capable of supplying sufficient radiation in the ultraviolet effectively to equal sunlight in therapeutic value and simultaneously to supply illumination in the visible range. The value of such an illuminant is stressed, in view of the ever increasing indoor activity of man with consequent deleterious physiological effects.

A rather complete account is given of the spectral energy distribution in sunlight under various local conditions and seasonal variations. The biological or physiological effects of various components of radiation are discussed in so far as the present day meager knowledge permits. An erythemal basis is suggested as a suitable measure of the biological effectiveness of an illuminant.

The problem of suitable fixtures for such dual purpose lighting, that is, the nature of the reflecting surfaces and transmitting media necessary to handle effectively both the visible radiation and the biologically-active ultraviolet radiation, is discussed. The permanency of these properties is considered in view of the known deleterious effects of ultraviolet radiation on these properties of materials.

The radiation characteristics of incandescent solids and electric arcs, particularly in regard to the ultraviolet radiation, is considered. This discussion leads to the details of the "Type S-1 Sunlight" lamp which consists of a mercury arc between tungsten electrodes at the terminals of a tungsten filament enclosed in a bulb of special glass. The utilization of this source as regards necessary fixtures, etc., is also discussed. Some fifty spectrograms showing radiation characteristics of this lamp and other sources together with absorption effects of some transmission media are appended.

The book is of interest technically in that it describes a new method of lighting involving not only visual radiation but also radiation in the spectral region known to have therapeutic value. There is much information on the character and properties of radiation produced by different sources which should be of interest to the medical profession. The manner in which the material is presented is such that the general reader should have no difficulty in following the subject. While the arrangement of the material is at times inconvenient, giving the impression of undue repetition, it does not detract from the value of the book as a whole.

R. D. Wyckoff

Lecture Experiments in Optics by B. K. Johnson, 110 pages. Edward Arnold & Co., London. $3.40.

This small handbook is "intended to serve as a convenient reference for the setting up of a number of lecture experiments in optics." The author does not attempt to discuss the theory underlying the experiments, but merely contents himself with describing the various demonstrations in geometrical and physical optics. A liberal use of diagrams is made, and the apparatus necessary for any experiment is carefully listed. The subject of total internal reflection might have been treated at greater length, due to the many applications in optical instruments and devices. Although the author suggests the use of an "optical smoke box" for some of the experiments, the path of a light beam can be just as vividly shown by the liberal use of chalk dust. The book will be found helpful to those who conduct lectures in general courses in light.

J. B. NATHANSON

Optical Activity and High Temperature Measurements. By F. M. Jaeger, University of Groningen. iii+450 pages. The McGraw-Hill Book Company, New York. $4.00.

This volume contains the lectures given by the author at Cornell University during the second semester of 1928–29 under the George Fisher Baker Non-Resident Lectureship in Chemistry.

The book begins with the text of Professor Jaeger's introductory lecture on the subject "The Present and the Future State of our Natural Resources"—which is a most interesting discussion of a world problem. Then follows Part I, on "The Spatial Arrangements of Atomic Systems and Optical Activity," which contains thirteen chapters. Several chapter titles will serve to indicate the scope of this section: Pasteur's Law and Asymmetric Atoms; Chemical Structure of Complex Inorganic Salts; Measurement of Optical Rotation; Complex Salts with Mixed Constituents; Asymmetrical Photosynthesis.

Part II is devoted to the "Methods, Results, and Problems of Precise Measurements at High Temperatures," as developed in the author's laboratory at Groningen during the past twenty years. Among the problems discussed are: the temperature coefficient of the surface tension of liquids between $-80°$ and $+1625°$C; measurement of the electrical conductivity of molten salts; precise measurements of specific heats of solids up to 1650°.

The book closes with a chapter on "The Constitution and Structure of Ultramarine."

One has a feeling that one is reading a book by an authority who not only writes from first hand knowledge, but who is so thoroughly conversant with the subjects discussed that he knows how to treat them simply and completely. The many data tables add materially to the value of the book, particularly for reference.

F. K. RICHTMYER